AD-771 029

FEASIBILITY STUDY OF A SILENT MULTIPURPOSE STUD DRIVER

FRANKFORD ARSENAL

OCTOBER 1972

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Small Arms Ammunition						
Propellant Actuated Stud Driver						
Lightweight Stud Driver						
Noiseless Stud Driver						
Stud Driver for Underwater Use						

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MEMORANDUM REPORT M72-27-1

FEASIBILITY STUDY OF A SILENT MULTIPURPOSE STUD DRIVER

BY

Thomas J. Hennessy
Charles A. Greenwood
Bohdan Sywak

AMCMS 5543.12.46809
DA Proj 1A542703D34609

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Munition Development & Engineering Directorate
FRANKFORD ARSENAL
Philadelphia, Pa. 19137

October 1972

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ABSTRACT

This study establishes the feasibility of a silent expendable stud driver. An investigation of commercial stud drivers led to the design of test devices and a preprototype model. The device weighs one pound and can drive studs capable of withstanding a minimum axial force of 250 pounds into structural steel, concrete, limestone, cinder blocks, and wood. The results indicated the feasibility of using one stud design and one propellant charge specification for all of the materials tested.

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INTRODUCTION

As a result of a visit to Fort Bragg, Frankford Arsenal learned of a potential military requirement for a stud driver which would operate effectively and silently into all ordinary construction materials and, if necessary, under water. This stud driver would be used as an aid to climbing or scaling and other similar tasks in which a quick, firm anchorage is needed. If such a stud driver were available, its requirements would be that it be effective, lightweight, waterproof, noiseless, and simple. This feasibility study is the first step in the development of such a stud driver.

Commercial stud drivers that drive studs into steel and concrete are readily obtainable. The studs can resist a withdrawal force of 250 pounds. Commercial stud drivers were not designed to be lightweight, noiseless, and waterproof, and were therefore not considered for the purpose of this study. However, initially commercial drivers were useful in obtaining data on approximate charges, forces, and performance, thereby saving considerable time.

Progress followed immediately from the initial studies and tests which verified that the basic ideas were sound. Confidence increased to the extent that predictable results occurred repeatedly, and eventually feasibility was demonstrated.

This report covers the experimental work on three test fixtures and the pre-prototype, leading to the demonstration just mentioned.

THEORY

General

Interior ballistics deals with the relationships between pressure, time, velocity, displacement, and the various propellant and gun parameters. Internal allistic relationships, particularly in the case of high velocity projectiles, are generally complex and not amenable to quick solutions. The nature of piston devices, however, is such that certain simplifying assumptions can be made that lead to more workable relationships without compromising accuracy. This is a consequence of the generally high ratio of piston to propellant mass and to the relatively low velocity imparted to the piston at the instant when all the propellant is burnt. The basic behavior of a piston device can be broken down into three stages:

1. Ignition of the propellant
2. Burning of the propellant
3. Expansion of the gases

In piston devices, the proportionate momentum of the piston is generally small at the end of stage 2, as most of its momentum is gained during stage 3. The equations that describe ballistic behavior in stage 3 are generally simple.

A cartridge for a piston device may, typically, be required to give the piston a specified energy at a controlled rate without the pressure ever exceeding some pre-chosen safe maximum. Available volume, temperature limitations, or other specifications may impose further constraints upon the design. By employment of a few fundamental principles plus ballistic experience and intuition. one can select the necessary combination of igniter, charge weight, and propellant burning characteristics. Although the equations used to describe the interior ballistics phenomena are generally complex, the basic principles can be given and described in fairly simple terms.

For a quick, reasonably accurate, first estimate of typical propellant pressures, we may first use the equation of state, which is the basic relationship between pressure, chamber volume, and temperature.

It is necessary also to consider the adiabatic relationship: if a quantity of propellant is burnt in a chamber of fixed volume, then

$$P(V - Cb) = CRT$$

where

P = pressure, psi

V = chamber volume, in.^{3}

C = weight of propellant, lb

b = covolume, the volume occupied by the propellant gas, generally about 26.3 in.^{3}/lb

R = propellant gas constant, generally about 768 in.-lb/lb° R*

T = absolute temperature = (459° + t) degrees Rankine

t = temperature in °F

At the instant the propellant burns in the chamber, the temperature is the adiabatic flame temperature, the temperature at which the gases are formed. Figure 1 is a graphical representation of this relationship for an assumed typical flame temperature of 6000° R. Note also that the perfect gas law is $PV = CRT$, which does not take the covolume into account.

Adiabatic Work Charts

For initial estimates of cartridge parameters, we assume that all the propellant is consumed before any work is performed. In the case of a piston device, therefore, this is equivalent to assume no piston motion until all the propellant is burnt. It is also generally

*A reminder here may be useful. R is the symbol for the gas constant, and is to be distinguished from °R, or degrees Rankine, the unit of temperature derived from the Fahrenheit scale but starting at absolute zero (= -459° F).

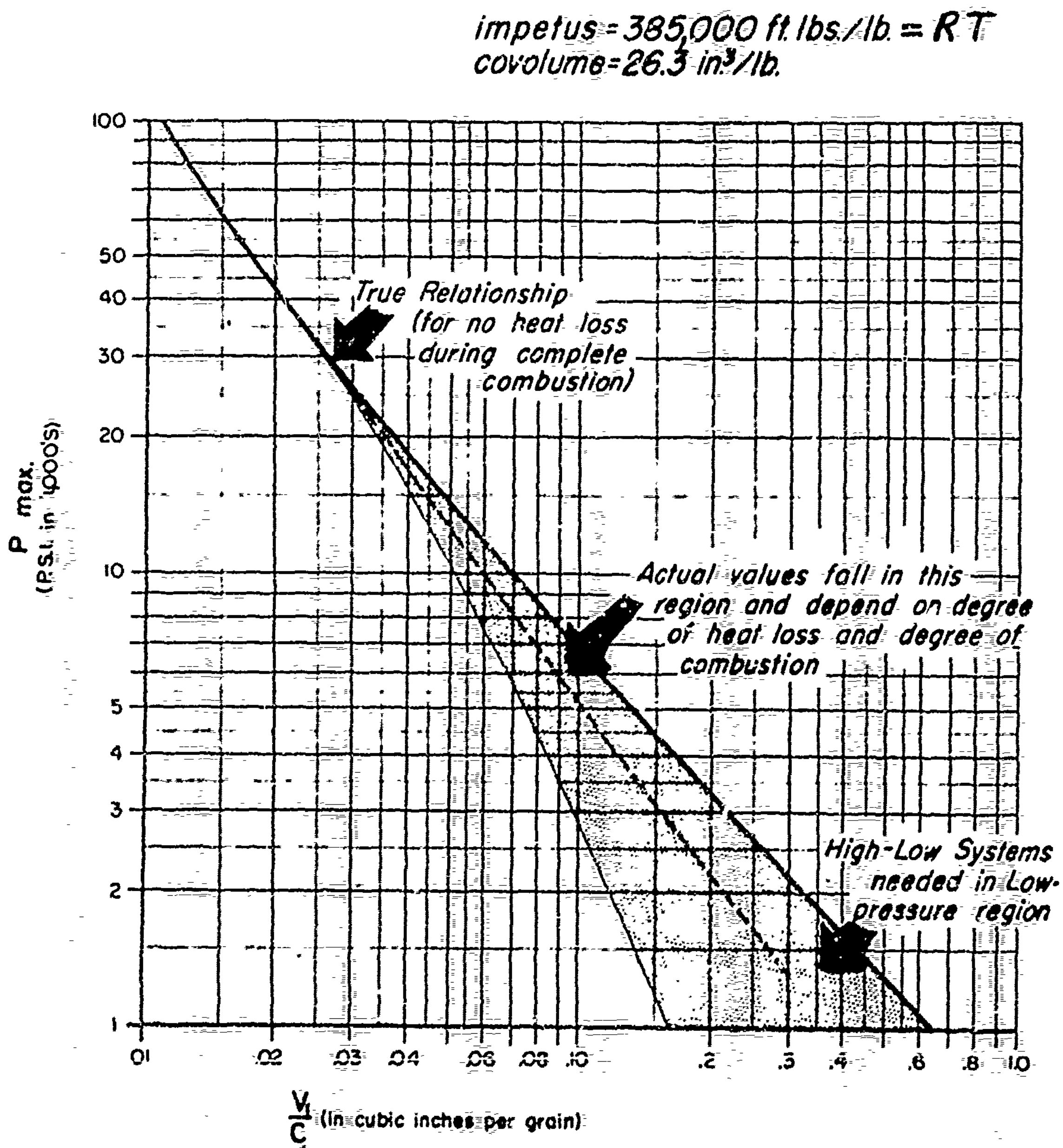


Figure 1. Equation of State - Relationship Between Pressure and Volume for High Energy Propellant

assumed that no heat is lost during motion of the piston, so that the gas expansion is adiabatic. The simple equations relating to piston motion are:

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{K-1} = \left(\frac{P_2}{P_1}\right)^{K-1/K}$$

and

$$P_1 V_1^K = P_2 V_2^K$$

$$K = 1.25 \text{ (generally for propellants)}$$

Figure 2 represents this relationship graphically. Figure 3 is a good description of the physical situation.

Let the propellant be all burned in an initial volume V_1 and at a maximum pressure P_1. The high pressure gases in this volume then move the piston. The total work performed during the expansion from the initial volume V_1 to some greater volume V_2 is equal to the area under the curve bounded by the dashed lines. Therefore, the total work is:

$$W = \int_{V_1}^{V_2} P\,dV = P_1 V_1^K \int_{V_1}^{V_2} \frac{dV}{V^K} = \frac{P_1 V_1 - P_2 V_2}{K - 1}$$

$$= \frac{P_1 V_1}{K - 1}\left(1 - \frac{P_2 V_2}{P_1 V_1}\right)$$

and since

$$P_1 V_1 = CRT,$$

and

$$\frac{V_2}{V_1} = \left(\frac{P_2}{P_1}\right)^{-1/K}$$

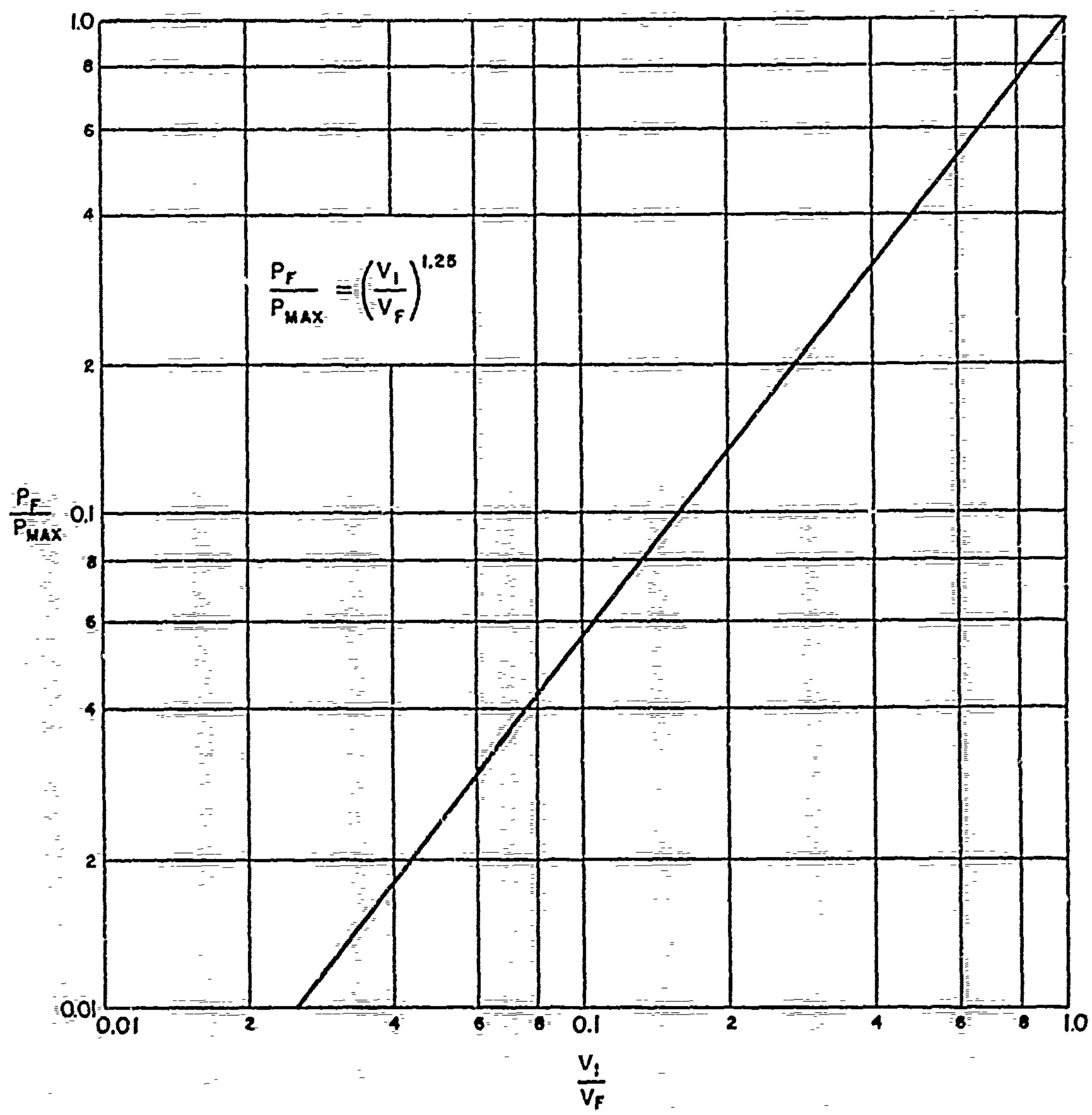


Figure 2. Relationship Between Pressure Ratio and Volume Ratio (initial to find) for Adiabatic Expansion

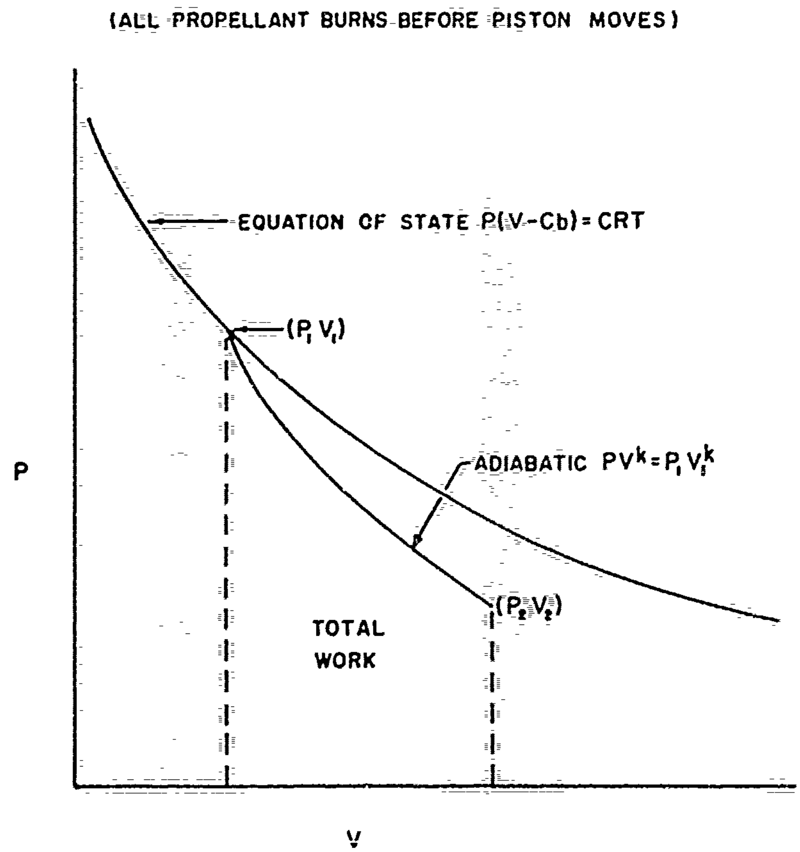


Figure 3. Energy of Piston for Case of Simple Adiabatic Expansion

then

$$W = \frac{CRT}{K - 1}\left[1 - \left(\frac{P_2}{P_1}\right)^{(K-1)/K}\right]$$

Figure 4 is a graphical representation of this relationship.

We now can use Figures 1, 2, and 4 in estimating cartridge parameters for the stud driver.

Cartridge design must proceed around certain preassigned values and limits; in this case these are 500 ft-lb of energy, a maximum pressure of 45,000 psi, 2.5 ounces of propelled mass, and a piston head diameter of 0.625 in. Given the above information, deduced from a commercial stud driver study, the following steps are taken to develop the required ballistic information:

1. Estimating Propellant Charge C. One grain of a typical propellant, if burned with no wasted energy, would liberate 200 ft-lb of energy. Reference to Figure 4, however, shows that we cannot even approximate this without having a very high ratio of initial to terminal pressure. To get any such amount of work out of the propellant would mean that the gas would have to cool to ambient temperature while all of its heat was being converted into work. This theoretical situation is virtually impossible, and the practical upper limit is 90-95 ft-lb/grain. Accordingly, if the ballistic situation permits a large expansion ratio, the propellant requirements can be estimated by allowing some 60-80 ft-lb/grain. Estimating 70 ft-lb/grain gives 7.1 grains for 500 ft-lb.

2. Estimating Initial Volume V_1. This is done with the aid of Figure 1. Given the amount of propellant, 7.1 grains as determined from step 1, and the maximum pressure, 45,000 psi from fixed parameters, the total initial volume is then easily determined from the figure. $V_1/C = 0.019$ in.^{3}/grain and $V_1 = C(V_1/C) = 7.1 \times 0.019 = 0.135$ in.^{3}. It should be pointed out that for a very fast-burning propellant, the initial volume is effectively the total chamber volume. For a slower-burning propellant, the piston will move before all of the propellant is burnt, so that maximum pressure will occur at a volume which may be about twice as large as the chamber volume.

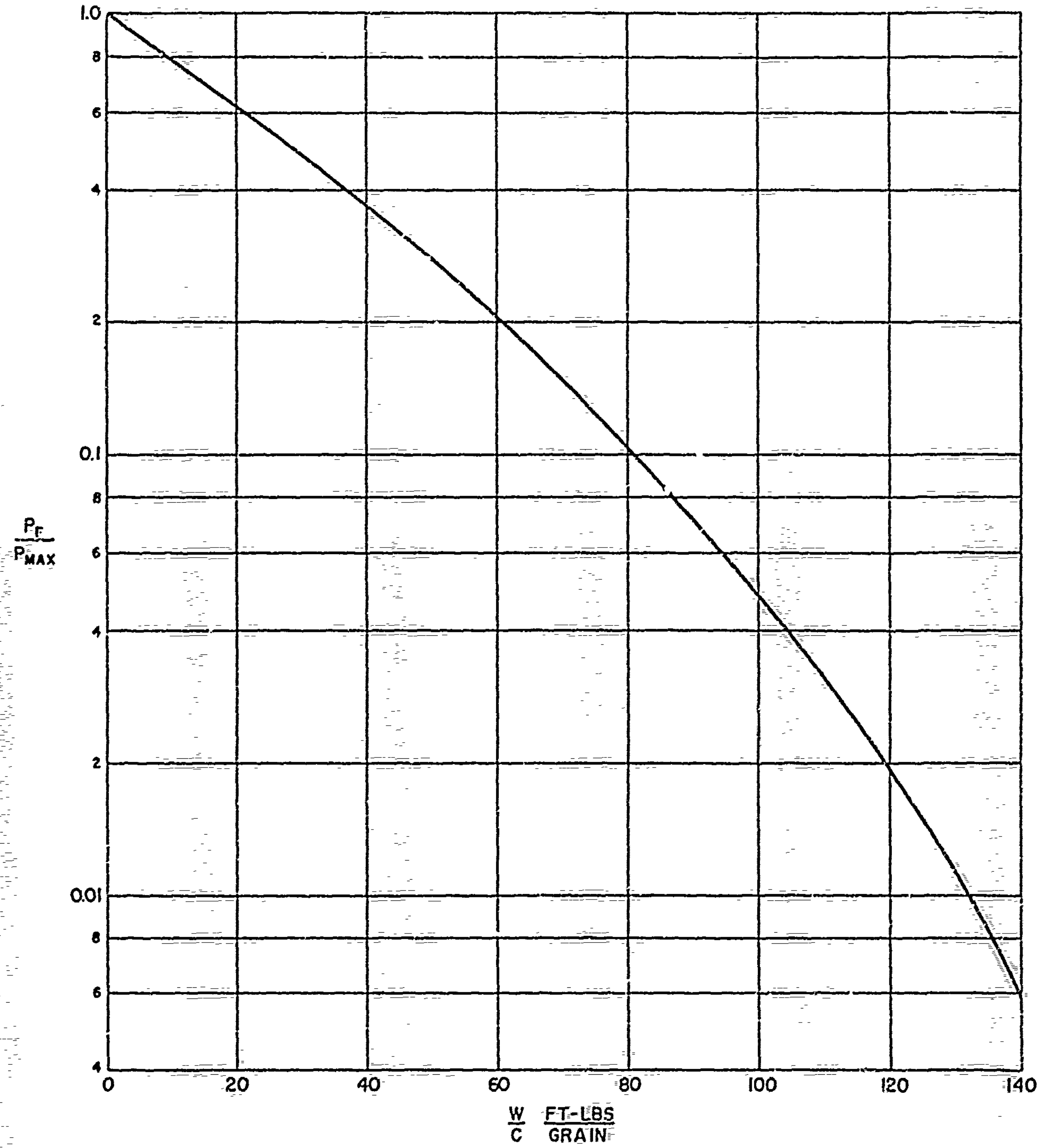


Figure 4. Relationship Between Pressure Ratio and Total Work (per grain of propellant) For Adiabatic Expansion

3. Estimating Pressure and Volume Ratios P_F/P_{max}. Figure 4 shows that for 70 ft-lb/grain, a pressure ratio of 0.145 is necessary; in practice it will be less than this due to heat loss. Reference to Figure 2 then shows that a pressure ratio of 0.145 is equivalent to a volume ratio of 0.215.

4. Estimating Final Volume and Pressure (V_F and P_F)

$$V_F = \frac{V_1}{V_1/V_F} = \frac{0.135}{0.215} = 0.628 \text{ in.}^3$$

$$P_F = P_{max} (P_F/P_{max}) = 45,000 \times 0.145 = 6500 \text{ psi}$$

5. Estimating Piston Area and Stroke (A_P and L_S)

$$D_P = 0.625 \text{ in. (Given)}$$

$$A_P = \frac{\pi}{4} D_P^2 = 0.785 (0.625)^2 = 0.307 \text{ in.}^2$$

$$\Delta V = V_F - V_1 = 0.628 - 0.135 = 0.493 \text{ in.}^3$$

$$L_S = \frac{\Delta V}{A_P} = \frac{.493}{.307} = 1.606 \text{ in.}$$

6. Establishing Cartridge Envelope. 7.1 grains of ball powder will fit in a caliber .38 special case.

REQUIREMENTS

Statement of Requirement

A potential requirement existed for a one-shot disposable stud driver, capable of driving studs into wood, metal, stone, ice, or concrete quickly and without noise, smoke, or flash. It will be compact, hand-held, lightweight, and propellant gas operated, capable of use in air or under water, for purposes of climbing and other tasks in which a quick, firm anchorage is needed.

Operational Concepts

1. The stud driver will be used mainly for tasks in which a quick, firm anchorage is needed.

2. The one-shot stud driver will be actuated by a quickly detachable, mechanically operated, reusable firing mechanism for use under any reasonable condition.

3. The firing mechanism and a supply of stud drivers may be carried on a belt or pouch.

4. The stud driver may be used to drive pitons into the face of stone or ice cliffs for climbing purposes.

Organizational and Logistical Concepts

1. The device will be used and controlled by military personnel having a need for the stud driver.

2. It will basically be an individual tool.

Reasons for Requirement

Experience indicates that an improvement must be made over the present methods of obtaining a quick, firm anchorage to various structures. Present techniques are cumbersome, time consuming, and unreliable. These methods require tying or driving nails or stakes to which an object may be attached or for the purpose of climbing.

Technical Feasibility

Although there are several commercially available stud drivers, the military requirements differ so greatly from the industrial that a development program was called for. The most conspicuous difference is the desire for a one-shot device, which can be abandoned after use, and which can be made much lighter because there is no problem of durability. Another major difference is the requirement for a single all-purpose charge and stud. Other requirements which commercial drivers are not usually expected to meet are low noise level, underwater capabilities, and applicability to stone (including granite). The feasiblity of the special requirements is within the scope of modern technology, although a moderate amount of development work is necessary.

Performance Characteristics

1. This stud driver will operate in any climate through the extremes of temperature (-40° F to +140° F) that may be encountered; it is to be waterproof; and the shelf life will be comparable to any self-contained ammunition.

2. Pressures should be in the neighborhood of 45,000 psi, and the energy required to penetrate the harder materials will be in the order of 500 ft-lbs.

3. The studs, when driven into solid materials, will resist an angular or axial force of at least 250 pounds.

4. The noise level will be restricted to that which is produced by the penetration of the stud into the materials.

Physical Characteristics

1. The weight of the firing mechanism will not exceed three ounces. The stud driver will not be in excess of one pound.

2. The firing mechanism will be approximately 0.5 inch in diameter by 4 inches long and the stud driver will be approximately 1 inch in diameter by 7 inches long.

5. No special packaging, maintenance, training, and safety precautions will be needed other than the normal ones for firearms.

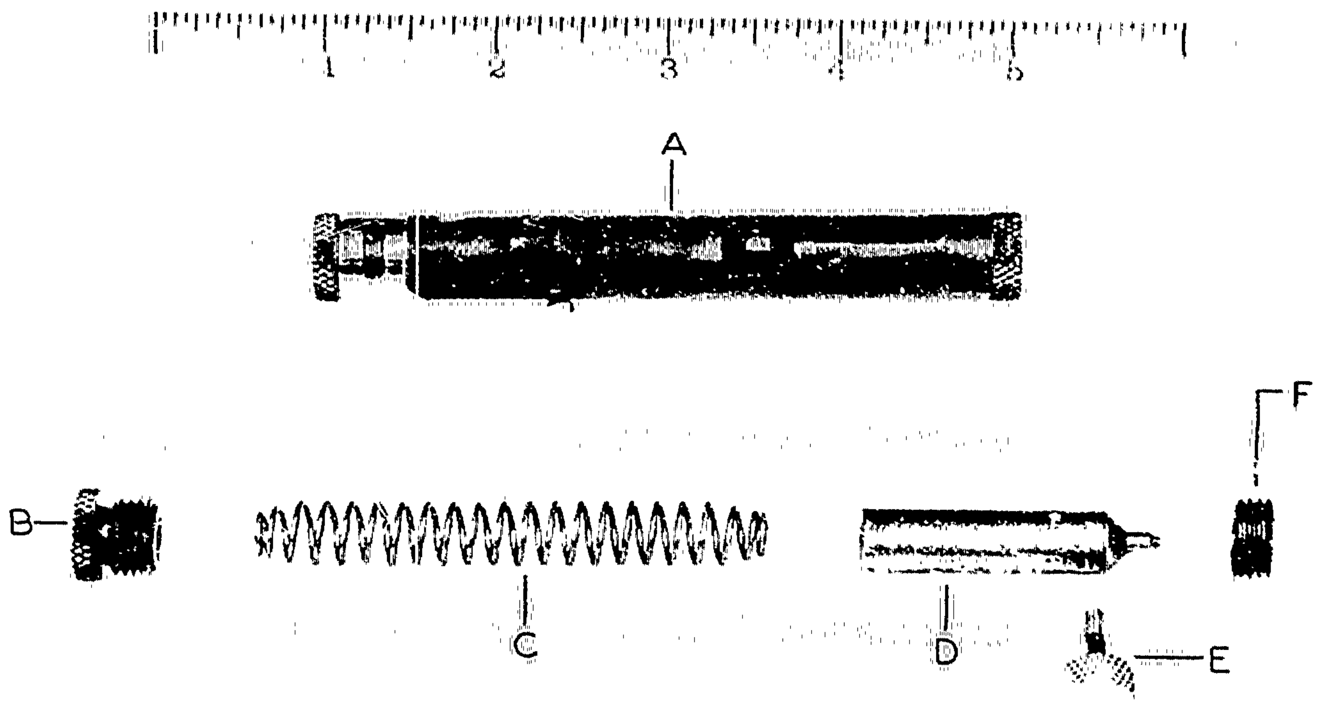
DESCRIPTION

The stud driver developed in this feasibility study consists of a firing mechanism and a driving mechanism.

The firing mechanism (Figure 5) comprises a tube containing a spring-driven firing pin, which has a handle projecting through a slot in the tube; the handle serves both to cock the mechanism, and to trigger it. Approximately, it is four inches long by a half-inch in diameter, and weighs two ounces.

The body of the driving mechanism (Figures 6 and 7) is an aluminum cylinder that accommodates the stud, the piston, and the propelling charge. The head of the piston (end nearest charge) has a greater diameter than the shank; the cylinder bore is stepped, having a 45° shoulder to fit the piston head at one end and the shank at the other. At the step of the bore is a wooden or aluminum crusher ring to cushion the piston at the end of its stroke. Means were provided to retain the propellant cartridge and to accept the firing mechanism. The stud is made of austempered steel, other steel parts of alloy 4340. The photograph, Figure 6, shows an enlarged head which is not indicated in the drawing, Figure 7; this is used with the test fixture attachment.

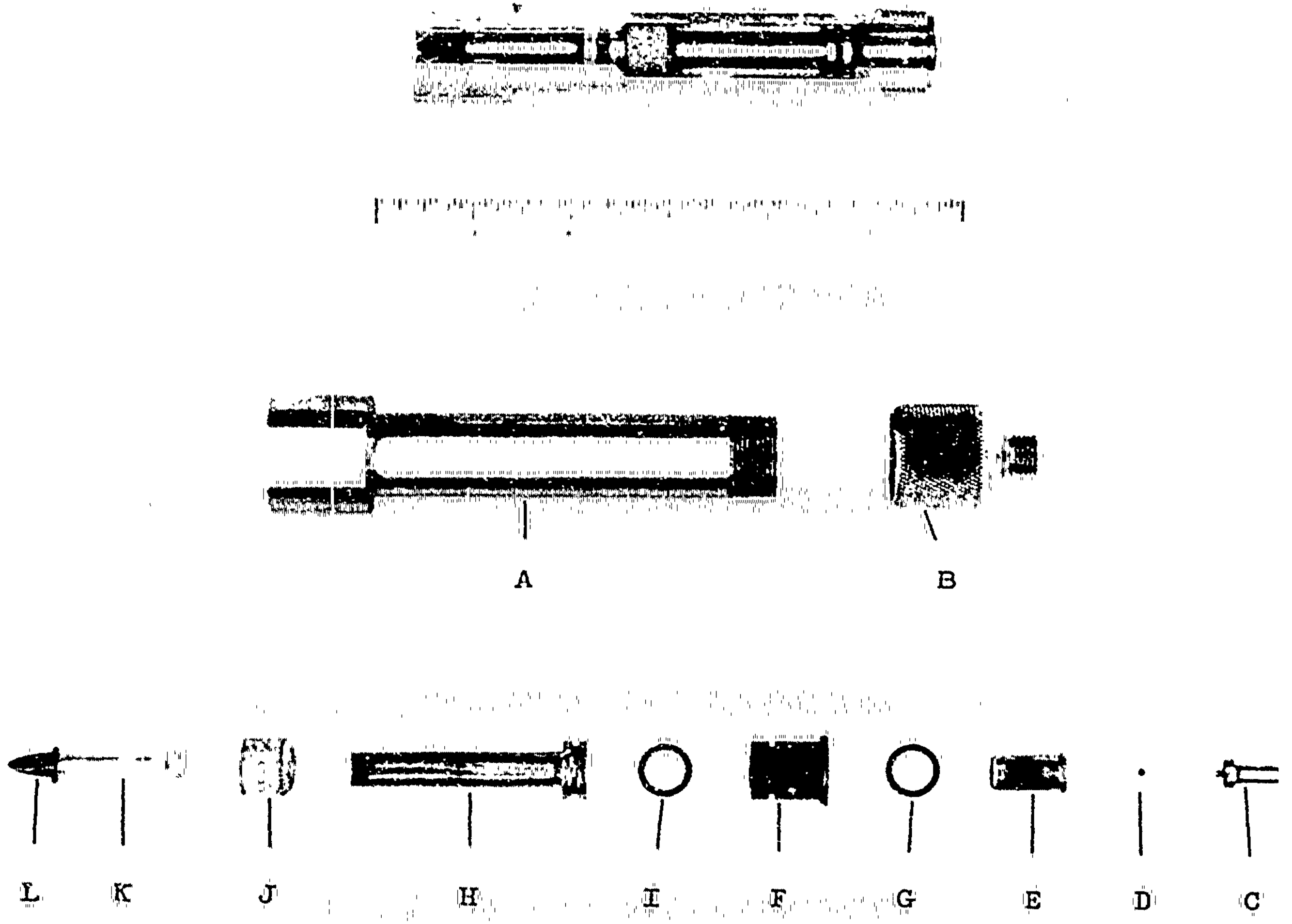
The preceding description is that of the preprototype; but the test fixtures differed somewhat so that they could be fired often and recharged readily. The most obvious difference is that the body of the test fixture was made in two parts, the body and the extension. The outside diameter of the body is 1-3/4 inches, instead of 7/8 inch as for the preprototype; it has an axial bore of 5/8 inch, to accomodate the piston head and the cartridge bushing, and a 1-3/8 inch thread for joining it to the extension. The extension has, beyond the internal thread to receive the body, a 3/8-inch hole for the stud and the piston shank; it also has an external thread for mounting into the



A. Tube
B. Cap
C. Spring

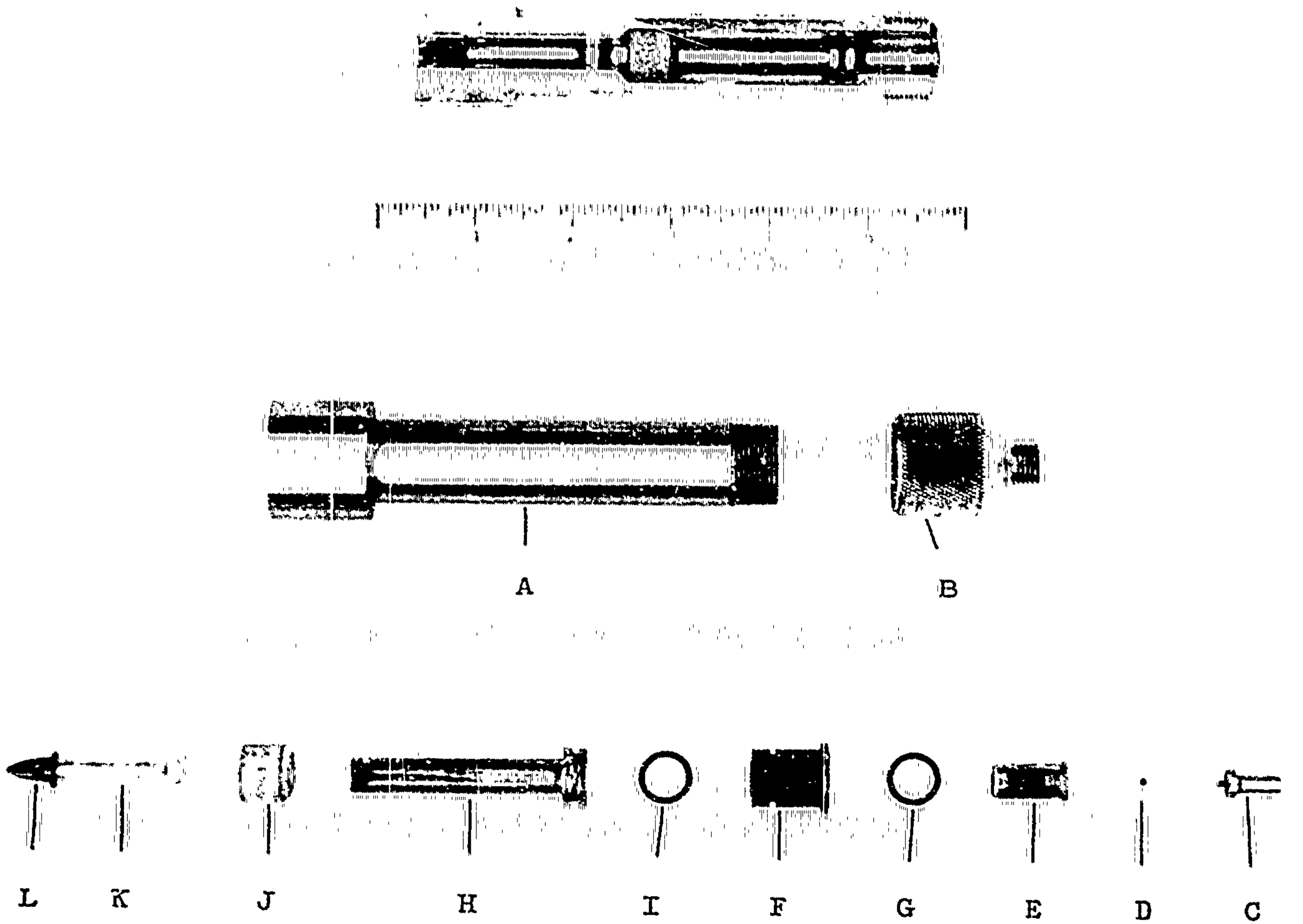
D. Firing pin
E. Firing pin handle
F. Firing pin guide bushing

Figure 5. Firing Mechanism Used With Prototype Stud Driver (A commercial device used to eject survival flares in emergencies)



A. Body
B. Firing plug housing
C. Firing plug
D. Firing plug bushing
E. Cartridge
F. Cartridge bushing
G. Cartridge bushing O-ring
H. Piston
I. Piston O-ring
J. Crusher
K. Stud
L. Plastic guide tip

Figure 6. Stud Driving Test Device Using Prototype Components (Exploded and Sectioned Assembly Views)



A. Body
B. Firing plug housing
C. Firing plug
D. Firing plug bushing
E. Cartridge
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G. Cartridge bushing O-ring
H. Piston
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Figure 6. Stud Driving Test Device Using Prototype Components (Exploded and Sectioned Assembly Views)

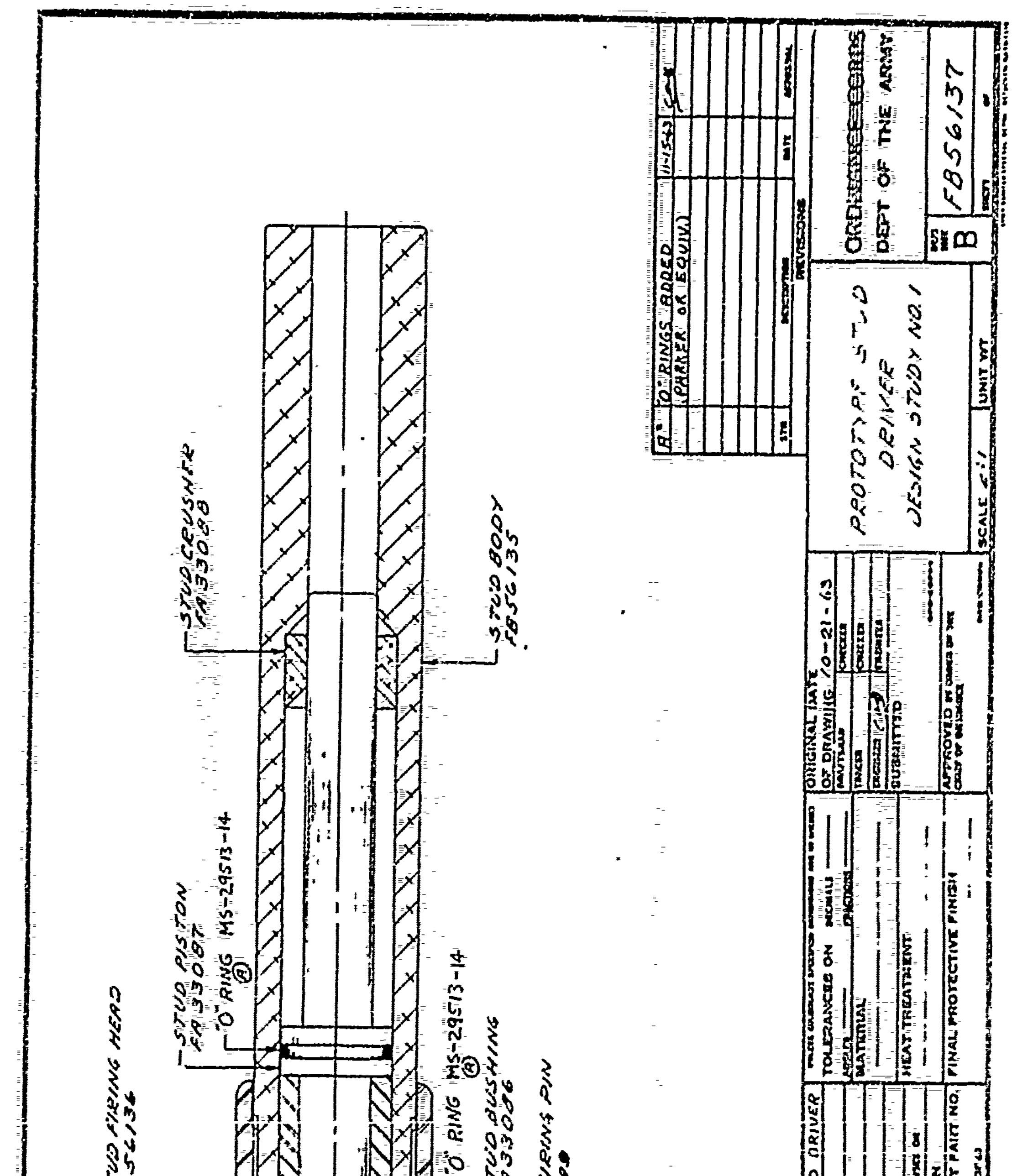


Figure 7. Prototype Stud Driver Design Study No. 1

clamp which attaches it to the target. An O-ring is used to seal the joint between the body and the extension. The crusher is made of aluminum and the firing plug housing differs from the one in the preprototype; but these differences are of no significance with respect to performance. The components are made of the same materials as the corresponding ones in the preprototype except that the preprototype crusher is wood; this difference in crusher material had no effect on performance. Figures 8 and 9 show the first of three test fixture designs.

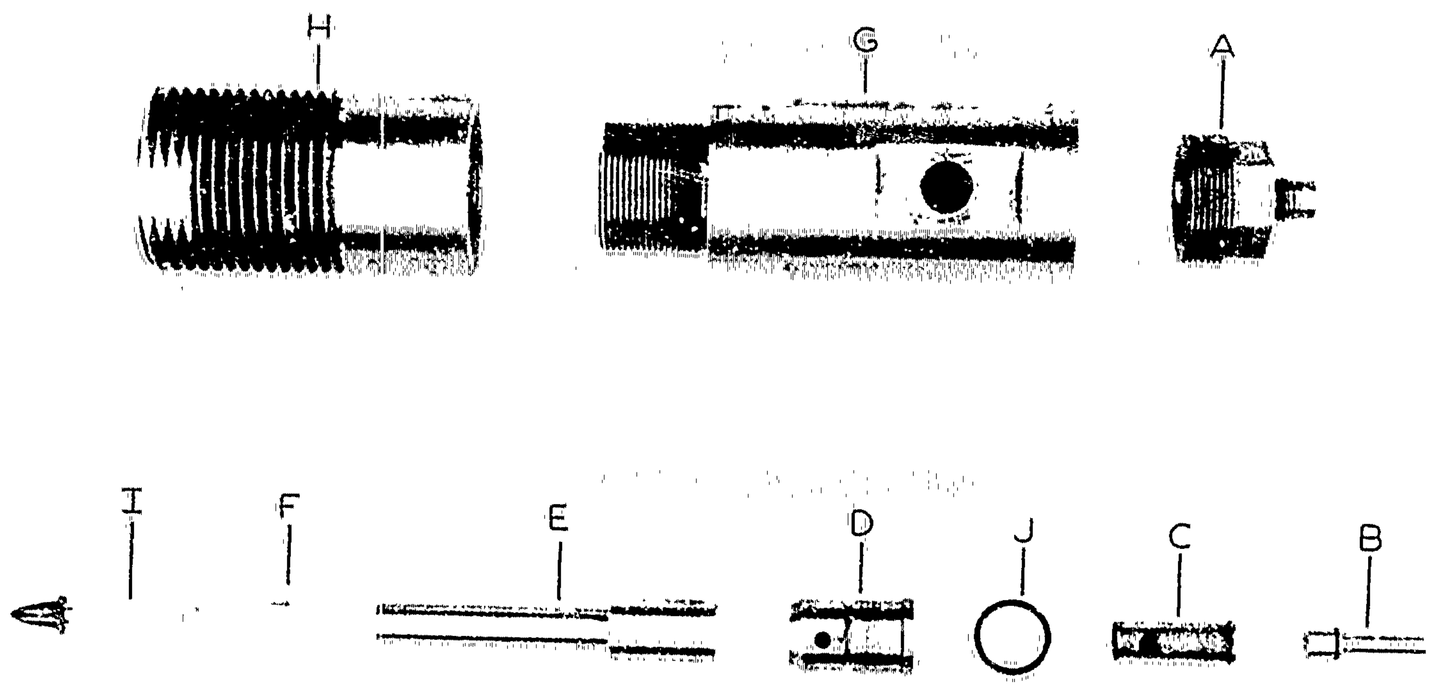
When the assembly is fitted with pressure instrumentation and attached to the target object (Figure 10),it is cocked by drawing the knob on the firing pin to the position shown in the figure, and then released by pushing the knob out of the detent, thereby firing the cartridge. The resulting propellant gas pushes the piston, which drives the stud into the material. The piston is stopped by the crusher between the piston head and the 45° shoulder. The distance traveled by the piston is equal to the length of the stud from the point to the underside of the stud's head, about 1-3/4 inches in most of the tests. Since the piston head traps the expanded gas behind it, a firing plug bushing (not shown in Figures 8 and 9 but shown in Figure 13) is used to keep the primer from blowing back. This eliminates fast gas leakage and possible damage to the components behind the primer. The system is silent because of the action of the piston.

A caliber .38 commercial propellant cartridge with 7.7 grains of WC 240 was the best cartridge and charge so far tested in the stud driver program. Commercial cartridges vary from caliber .22 to caliber .38 with charges from 1.6 grains to 13.4 grains. The propellants used with commercial stud drivers include WC 420, WC 370 and WC 350.

MATERIAL AND TEST EQUIPMENT

1. Standard 8-inch commercial channel iron (See Figure A-1).

2. Coarse concrete building block, 8 x 8 x 16 inches, solid, aged 9 years.



A. Firing plug housing
B. Firing plug
C. Cartridge
D. Cartridge bushing
E. Piston
F. Crusher
G. Body
H. Extension
I. Stud
J. Cartridge bushing O-ring

Figure 8. Stud Driving Test Fixture No. 1 Used to Obtain Preliminary Design Data (Exploded View)

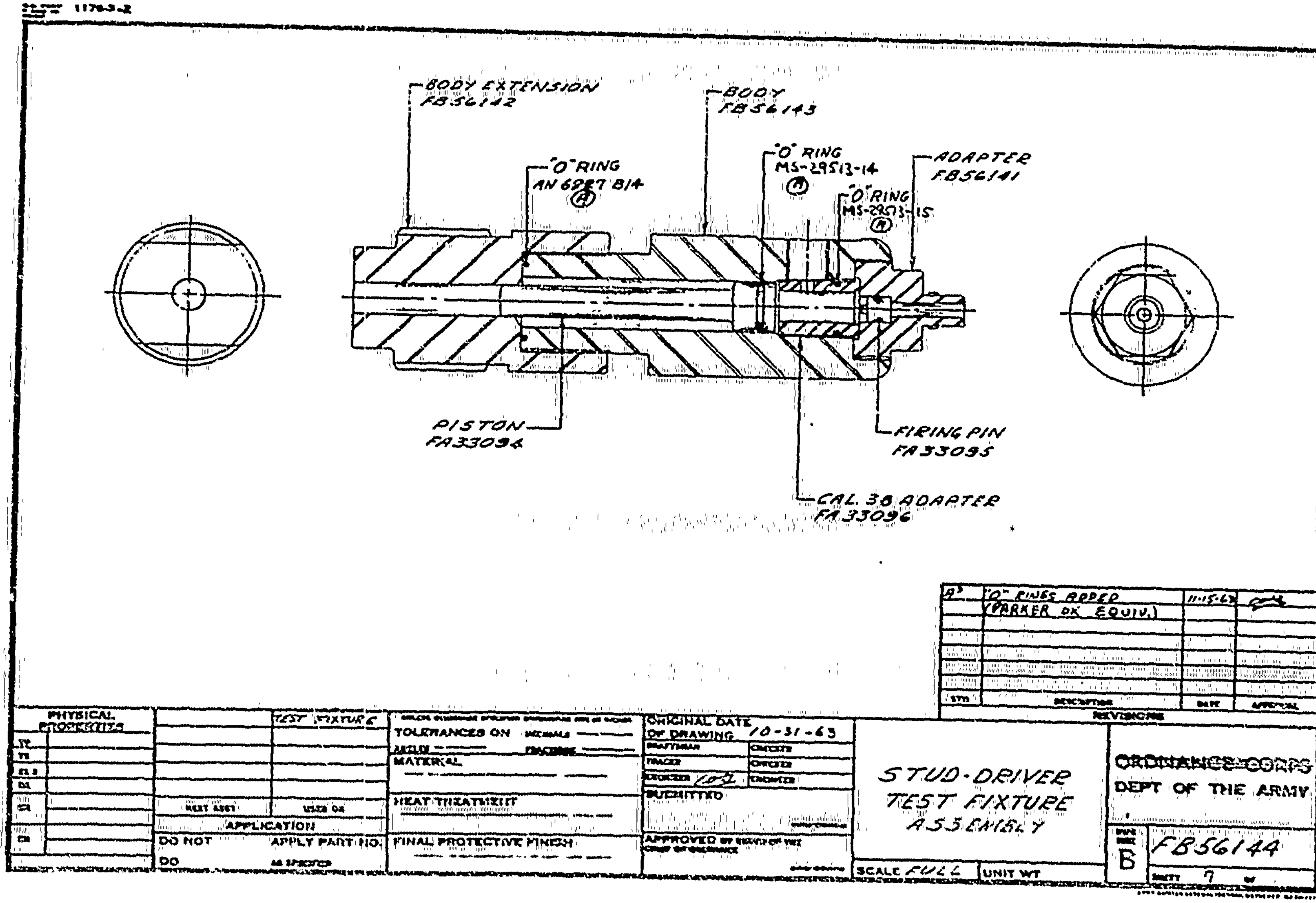
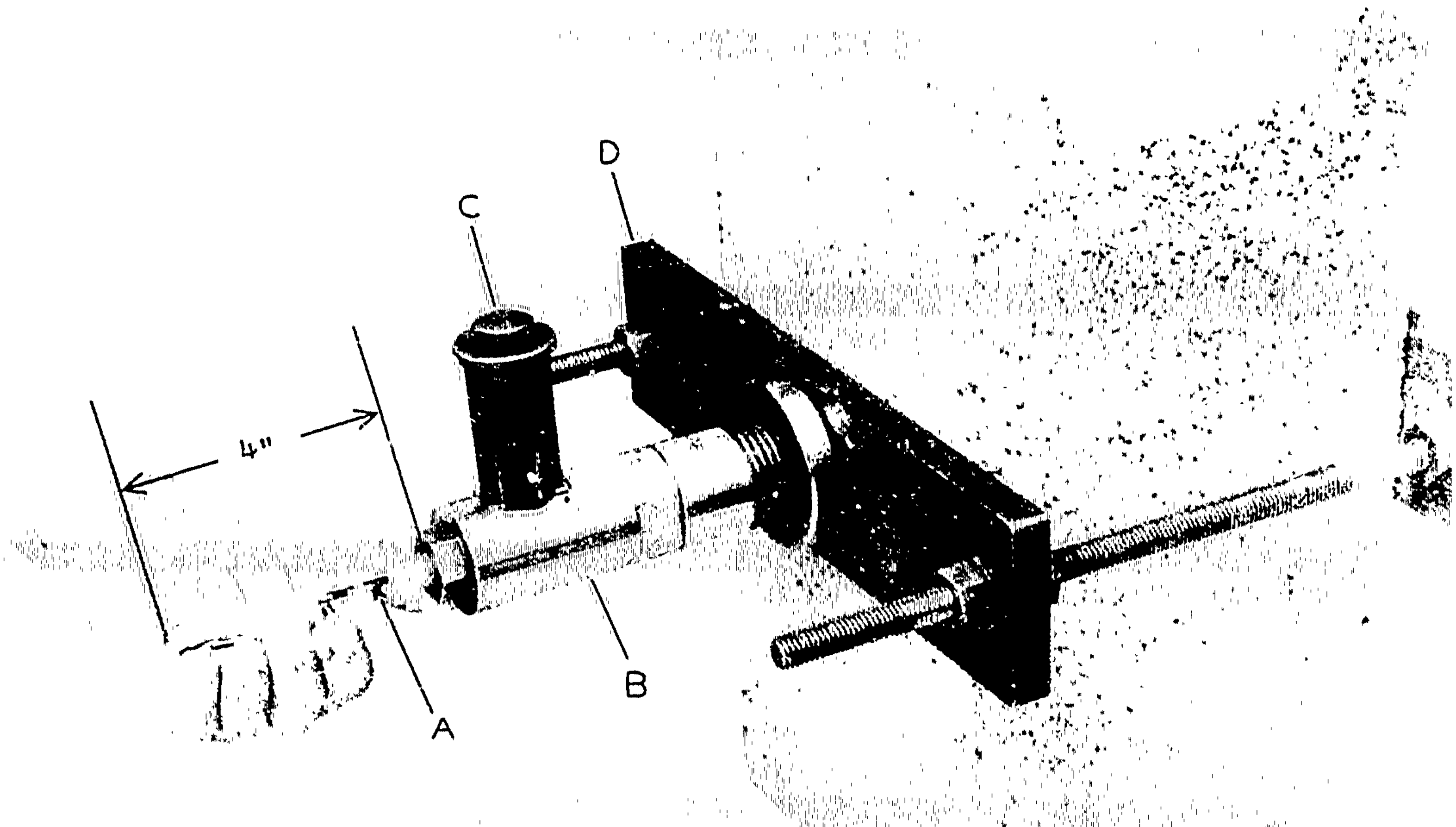


Figure 9. Stud Driver Test Fixture Assembly



A. Pen Gun C. Pressure Gage
B. Test Fixture D. Clamp

Figure 10. Stud Driver Test Fixture

Arrangement shows method used to obtain experimental data for driving studs into concrete building blocks. Firing mechanism (A), a standard commercial flare ejector, is used to initiate primer. Pressure gage (C) attached to fixture (B) is used to record peak pressure. Clamp (D) holds assembly together and facilitates safe firing of the fixture.

3. Finish concrete block, 8 x 8 x 16 inches, solid, not aged.

4. Finish limestone block, 8 x 8 x 16 inches, solid, not aged (See Figure A-2).

5. Standard cinder block, 8 x 8 x 16 inches, solid, not aged.

6. Finish lumber, 4 x 4 inches, fir wood.

7. Standard printed circuit paper.

8. Copper pressure cylinders, lot 2C-62.

9. Pitman-Dunn Laboratories, Frankford Arsenal, pressure gage, 1/30 in.^{2} piston, collet for copper pressure cylinders (see Figure 10).

10. Pitman-Dunn Laboratories, Frankford Arsenal, piezo-electric gage, No. 22 (Gage constant = 503).

11. Universal counter-timer, Computer Measurements Company, Model 726B.

12. Standard pendulum, 268 pounds, 3.44 sec/cycle.

13. Tatnall Metafilm strain gages, The Budd Co., Type: C12-121-R2B; resistance: 120 ± 0.2 ohm; gage factor: 2.00 ± 1/2%; log No.: A4-G-17.

TEST FIRING PROCEDURE

The step-by-step procedure in preparing the test setup is given below.

1. The stud was inserted into the extension, so that the tip was flush with the output face. If standoff tests were being run, a longer extension was used and the stud inserted to the required distance.

2. The O-rings were placed into position on the various components.

3. The crusher was slid onto the piston shank, beveled face toward the head, and both were then inserted into the body, piston head first.

4. The cartridge was placed in the cartridge bushing and both into the body, taking care that the pressure holes are aligned.

5. The firing plug was put into the housing, and the bushing pressed into place.

6. The attaching clamp for the fixture was fastened firmly to the target material.

7. The extension was screwed into the clamp, the body into the extension, and the firing plug housing into the body.

8. The pressure gage was screwed into the side of the body.

9. The firing mechanism (in its safety position), a commercially available "Pen-Gun", was screwed onto the firing plug housing.

10. The device was cocked by drawing the knob of the "Pen-Gun" against the spring and into the detent slot. The device was fired by pushing the knob out of the detent.

The data recorded are:

a. Test title, and type of test fixture.

b. Date.

c. Round number.

d. Type and quantity of propellant.

e. Type of stud.

f. Type of target material.

g. Standoff, if any.

h. Pressure and pressure-measurement system.

i. Penetration.

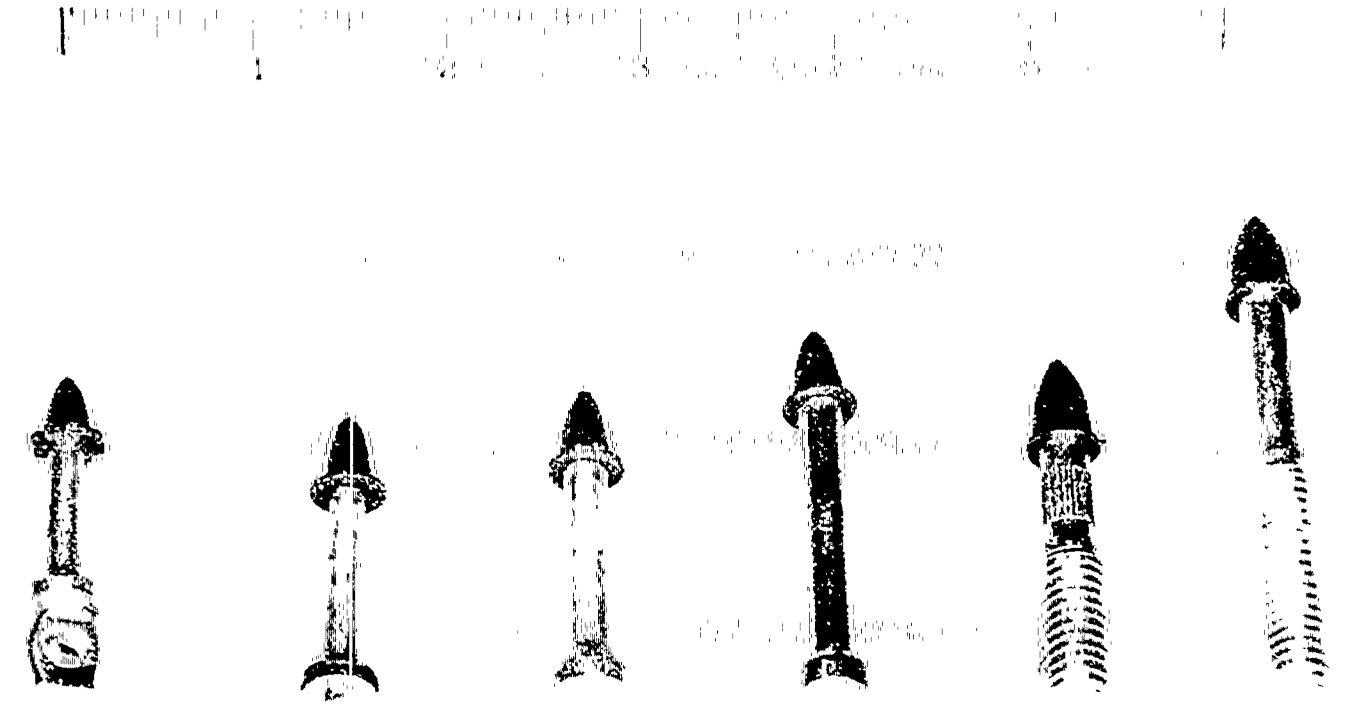
METHOD

The analysis of commercial stud drivers preceded the design of the original test fixture. Testing of three commercial stud drivers, while the fixtures were being made, supplied information useful to the program. (Figures 11 and 12 show a typical commercial driver and studs.) This information indicated what to expect under similar conditions with the test fixture as well as the inadequacies of commercial drivers for Special Forces. Testing of the commercial units ended when the special test fixture became available for experiment. Use of commercial charges and studs with the fixture led to encouraging results. Pressures and penetrations in several types of materials were the most important aspects of the results.

Encouraged by the performance of the first test fixture, Frankford Arsenal proceeded with the fabrication of a preprototype (Figure 6). Initially, the preprototype compared favorably with the test fixture; however, differences appeared during the stage of charge establishment for penetration of 7/16-inch thick steel. This material offered the greatest resistance to penetration, yet it was likely that the thickness of 7/16-inch was an entirely realistic requirement.

The design and fabrication of another test fixture, more like the prototype, was the next logical step. Studies with this modified test fixture, Figures 13 and 14, began with another attempt to establish a charge of WC 350 propellant which would accomplish the most difficult task required of it. (The photograph does not show the hole for pressure instrumentation.) It soon developed that pressures and penetrations were erratic, which led to the investigation of other propellants of which, at first, the most promising was WC 240. Later, however, the same problem of erratic performance recurred, but WC 240 still

Figure 11. A Commercial Stud Driver



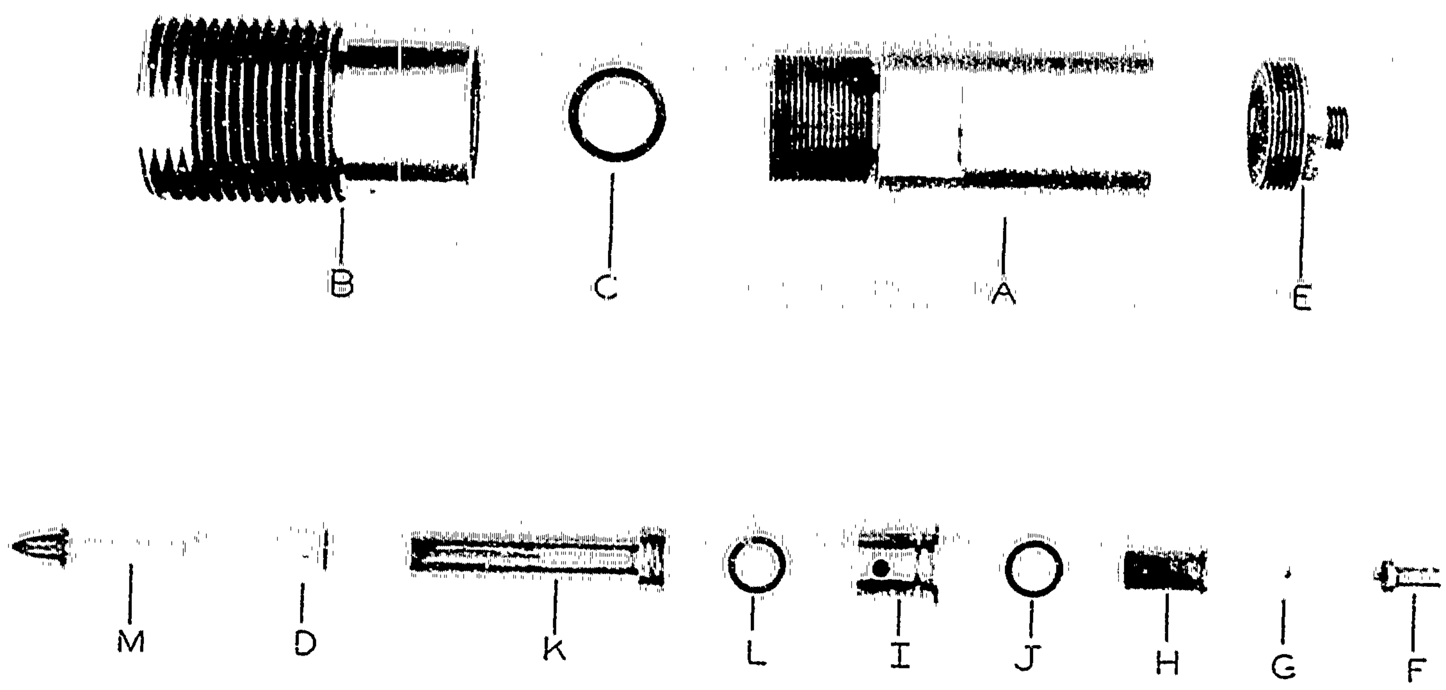
A B C D E F

A. No. 3601
B. No. 3335
C. No. 3317

D. No. 3318
E. No. 3441
F. No. 3439

Figure 12. A Sample of Commercial Studs

(A, C and D were used in tests.)



A. Body
B. Extension
C. Body-extension joint O-ring
D. Crusher
E. Firing plug housing
F. Firing plug
G. Firing plug bushing
H. Cartridge
I. Cartridgo bushing
J. Cartridge bushing O-ring
K. Piston
L. Piston O-ring
M. Stud

Figure 13. Stud Driving Test Fixture No. 2 Used to Evaluate Prototype Components (Opening in "A" for pressure instrumentation is not shown)

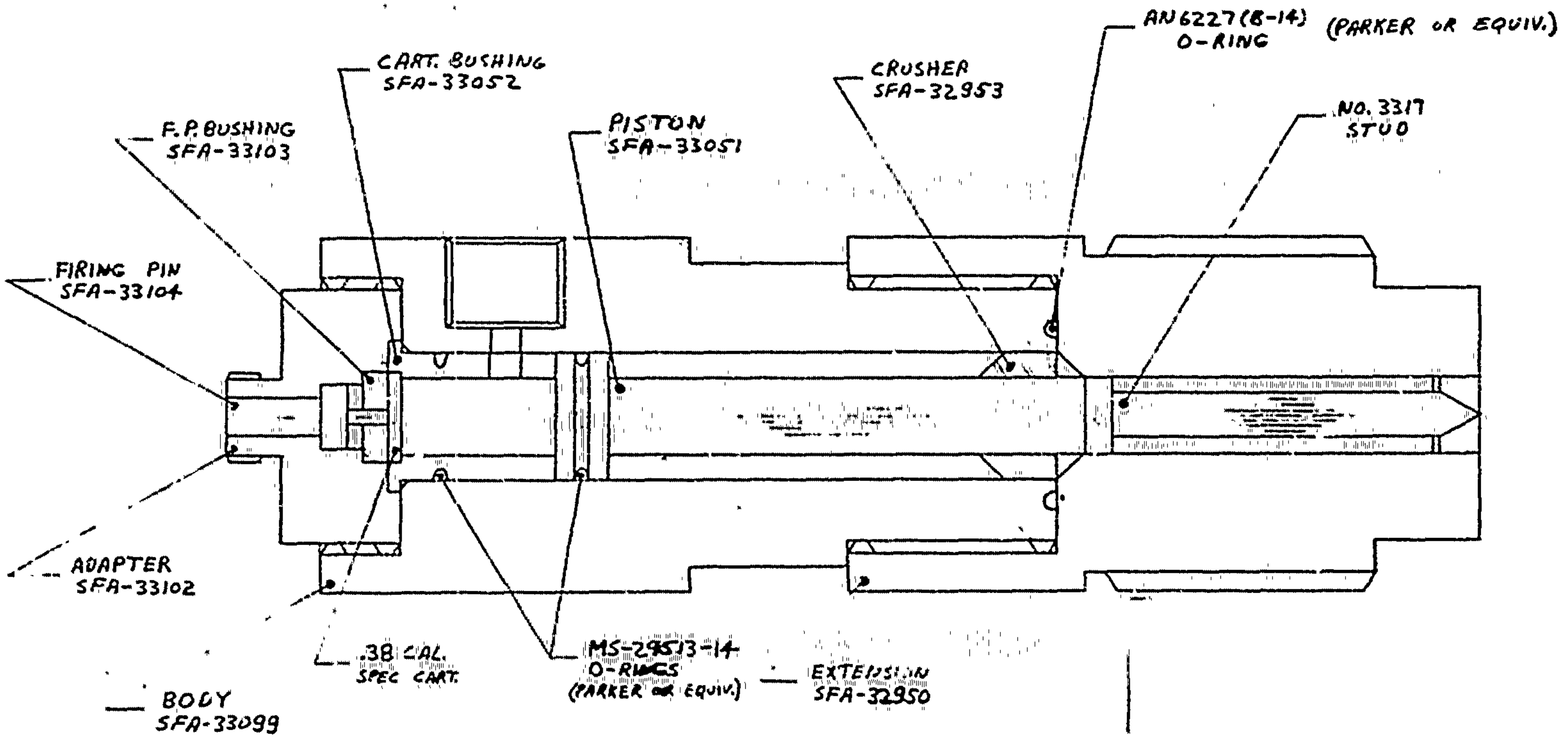


Figure 14. Stud Driver Modified Test Fixture Assembly

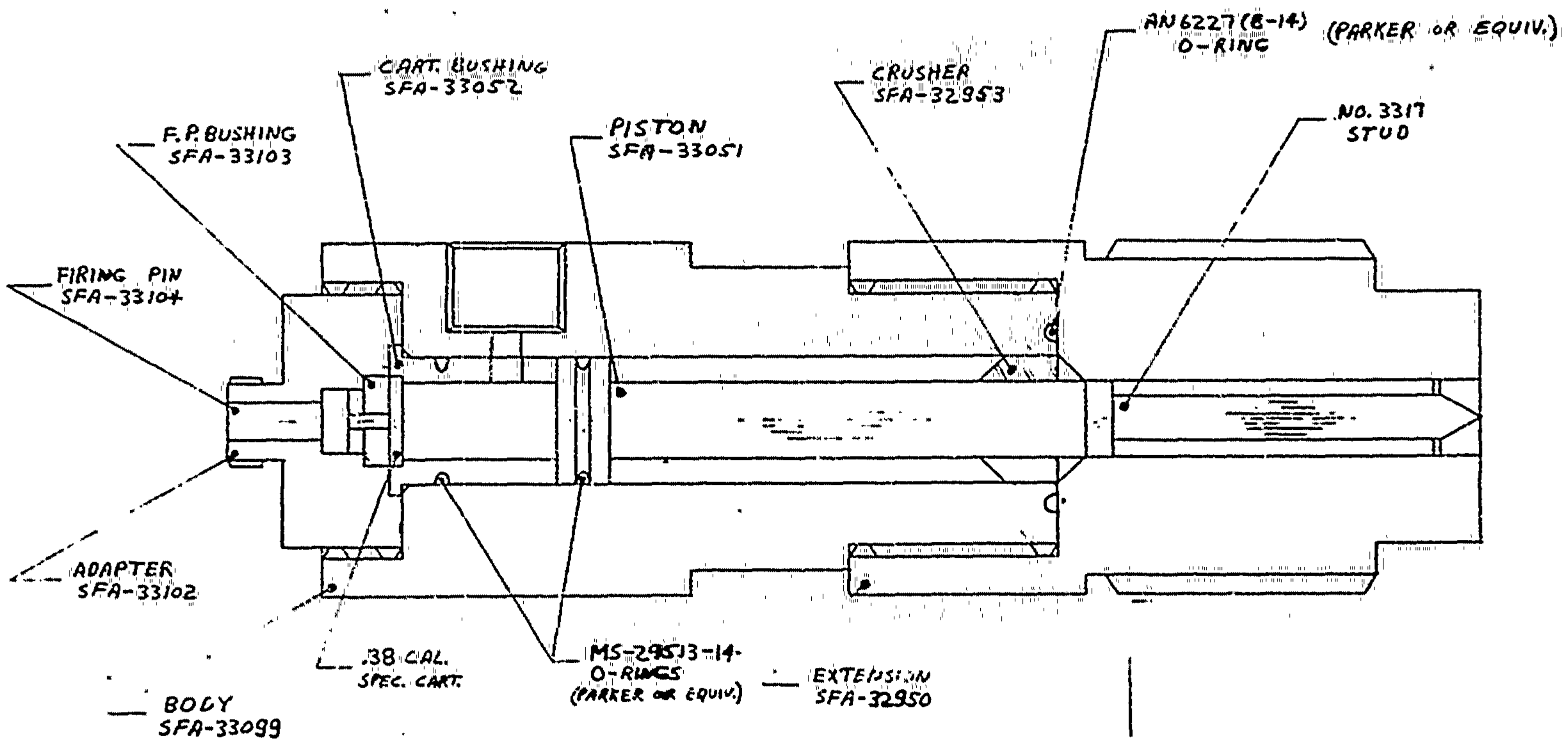
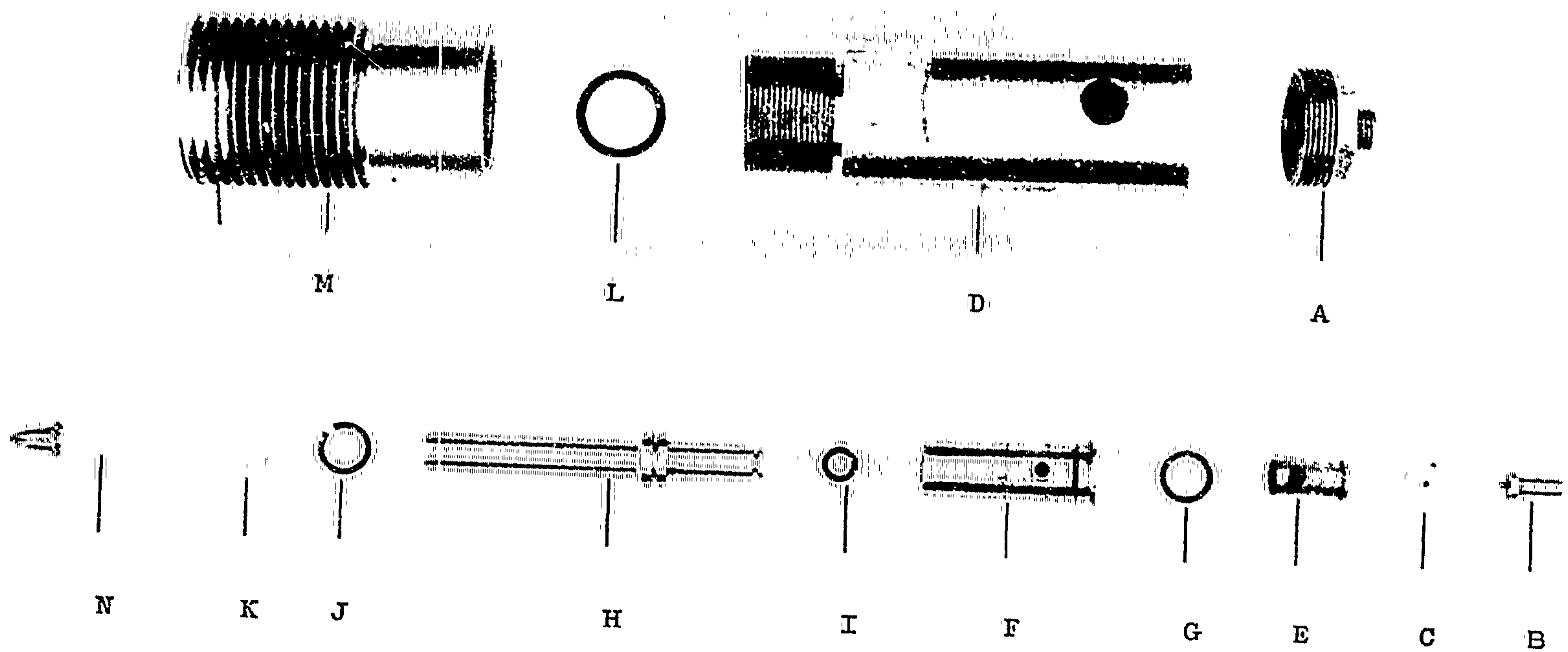


Figure 14. Stud Driver Modified Test Fixture Assembly

behaved better than WC 350. The next attack against this problem was the use of standoff in the system. (Standoff is the distance between the stud and the target material; by using standoff, the stud can gain velocity in the barrel before striking the material.) This led to successful penetrations but the erratic pressures remained.

After re-evaluating the system, the use of a high-low pressure system appeared to be advantageous and a suitable design was evolved (Figure 15). This system incorporated a double-shanked piston, which would allow the pressure to stay at a high value until the system had completed most of its work, and then drop off rapidly. The real advantage of this system, though, was that the gas would expand into a chamber of the same diameter rather than into one of a larger diameter. The immediate expansion of the gas from a 3/8-inch diameter chamber to one of a 5/8-inch diameter could very likely have caused inconsistency in the other systems. Following the fabrication of a high-low test fixture, Figure 15, experiments began once more. Although the pressures were consistent and high, not one stud penetrated 7/16-inch thick steel properly. (Proper penetration is the seating of the stud head against the target material.) The P-T curves of this system showed a slower ballistic cycle than the others, which explains the penetration failure. One of the curves is given in the Appendix. The demonstration of the stud driver at Picatinny Arsenal and the subsequent canceling of the project ended exploration at this point, except for some recoil and velocity experiments.

All of the development work was on the driving mechanism. since the commercially available "Pen-Gun" (Figure 5) served as the firing mechanism. This device met all of the requirements for the firing mechanism, and its use in most of the program showed its suitability.



A. Firing plug housing
B. Firing plug
C. Firing plug bushing
D. Body
E. Cartridge
F. Cartridge bushing
G. Cartridge bushing O-ring
H. Piston
I. Piston shank O-ring
J. Piston head O-ring
K. Crusher
L. Body-extension joint O-ring
M. Extension
N. Stud

Figure 15. Stud Driving Test Fixture No. 3 Used to Evaluate the Prototype High-Low Ballistic System (Exploded View)

RESULTS AND DISCUSSION

Test results are summarized in Tables I and II. In the first experiment using the original test fixture, the results in Table I-A were encouraging. All penetrations were proper and the pressures were reasonably uniform except for the first and last rounds. There was no apparent reason for these two abnormally low values. The data in Table I-B showed the pressures and penetrations to be acceptable considering the early stage of development, although some penetration was light. Table I-C shows how the pressures and penetrations varied in different materials. All penetrations were acceptable and the pressures usually varied according to the resistance of the materials. The two trials involving washers showed similar pressures which, for some unknown reason, were markedly lower than the others. Table I-D reveals the 7/16-inch thick steel offered the greatest resistance to penetration, as indicated by the amount of propellant and by the high pressures, these results were not discouraging. Either better pressure consistency or more propellant appeared to be the answer for perfect penetrations, and a prototype now seemed feasible.

Table I-E shows the original results of the prototype tests. For penetrating limestone, the required charge was less in the prototype than in the original test fixture, and the pressures were considerably higher. The cause of some of the differences in pressure readings was probably the use of a different system of measurement. Because this was to be a test of a prototype stud driver, strain gages were used instead of copper pressure cylinders. Higher pressures and smaller charges were expected, since the prototype was more efficient.

Table I-F indicates that the pressure consistency when driving in 7/16-inch thick steel was still poor but better than that of the original test fixture. The better performance of the prototype, and the difficulty of obtaining uniform pressures, when it was tested, prompted the design and fabrication of another test fixture more like the prototype. The original test fixture had a longer and heavier piston, cartridge case, and firing plug, and had no O-r. .gs nor a firing plug guide bushing to seal the gases more effectively during the ballistic cycle.

Table I-G is evidence that acceptable penetrations occurred as frequently in the modified test fixture as they did in the prototype;

but consistency of penetration was still poor, apparently because of the inconsistent pressures. (The last shot may have been border line.) The modified test fixture required about the same charge as did the prototype, under similar conditions.

The possibility of having too high a loading density, causing inconsistency, led to the use of less propellant; Table I-H gives the results of this. The penetrations improved but the pressures did not.

The use of a piezo-electric gage instead of copper pressure cylinders to obtain the pressures was the next experiment since the pressures were less consistent than the penetrations. Table I-I shows even poorer results.

There seemed no advantage in continuing the same line of testing. A commercial stud driver propellant, WC 350, performed well in the original test fixture; therefore investigation of other propellants had not seemed necessary. But at the present stage of development, it appeared that it might be profitable to explore other propellants. In Table I-J, the results showed that Red Dot, AL-8 and IMR 3031 propellants were not suitable for use with the fixture. They are either too slow or not powerful enough. (Low impetus.)

Table I-K shows that WC 240 propellant acted very well with almost perfect penetration and fairly consistent pressure for this system. But further tests, reported in Table I-L, revealed that uniformity of pressure had still not been achieved.

The test fixture's extension was replaced by a longer one to provide standoff. Table I-M shows that 3/4-inch of standoff proved successful for perfect penetrations, but pressures remained inconsistent. The continuing search for a solution to the pressure problem led to the design and fabrication of a new test fixture with a high-low pressure system. Table I-N shows the performance of the high-low test fixture; and the results are divided into two groups of indicated pressure level. The only differences in the test conditions of these groups were the dates and pressure measurement systems.

The cancellation of this project ended the testing of this fixture before the determination of its feasibility.

The recoil and velocity results using the modified test fixture are presented in Table II. When penetration was proper, the recoil was

TABLE I.

Summary Performance

Rd	Charge Type	Charge Grains	Stud No.	Target Material	Target Penetration *	Pressure psi	Pressure Method
				A. Original Test Fixture			
1	WC 350	7.6	3335	limestone	proper	3100	copper cylinder
2	WC 350	7.6	3335	limestone	proper	9400	copper cylinder
3	WC 350	7.6	3335	limestone	proper	8600	copper cylinder
4	WC 350	7.6	3335	limestone	proper	10000	copper cylinder
5	WC 350	7.6	3335	limestone	proper	10200	copper cylinder
6	WC 350	7.6	3335	limestone	proper	9300	copper cylinder
7	WC 350	7.6	3335	limestone	proper	8700	copper cylinder
8	WC 350	7.6	3335	limestone	proper	9500	copper cylinder
9	WC 350	7.6	3335	limestone	proper	6500	copper cylinder
				B. Original Test Fixture			
1	WC 350	6.0	5/2965	concrete	1/8"	12000	copper cylinder
2	WC 350	6.0	5/2965	concrete	1/8"	11500	copper cylinder
3	WC 350	6.0	5/2965	concrete	proper	9200	copper cylinder
4	WC 350	6.0	5/2965	concrete	proper	9500	copper cylinder
				C. Original Test Fixture			
1	WC 350	6.0	5/2965	wood	3/8"	7200	copper cylinder
2	WC 350	6.0	5/2965	cinder	proper	8600	copper cylinder
3	WC 350	6.0	5/2965	wood	proper	4200	copper cylinder
4	WC 350	6.0	5/2965	cinder	proper	4500	copper cylinder
5	WC 350	6.0	5/2965	wood plus 1/16" steel	proper	11400	copper cylinder
				D. Original Test Fixture			
1	WC 350	9.5	3317	7/16" steel	7/16"	17000	piezo gage
2	WC 350	9.5	3317	7/16" steel	7/16"	14000	piezo gage
3	WC 350	9.5	3317	7/16" steel	proper	19500	piezo gage
4	WC 350	9.5	3317	7/16" steel	proper	19000	piezo gage
5	WC 350	9.5	3317	7/16" steel	7/16"	17500	piezo gage
				E. Prototype Driver, Charge Established			
1	WC 350	6.0	3317	limestone	1/8"	22000	strain gage
2	WC 350	7.0	3317	limestone	proper	30000	strain gage
				F. Prototype Driver			
1	WC 350	9.2	3317	7/16" steel	3/8"	omitted	
2	WC 350	9.2	3317	7/16" steel	proper	omitted	
3	WC 350	9.2	3317	7/16" steel	3/8"	omitted	
4	WC 350	9.2	3317	7/16" steel	3/8"	omitted	
5	WC 350	9.2	3317	7/16" steel	3/8"	omitted	
6	WC 350	9.2	3317	7/16" steel	3/8"	omitted	
7	WC 350	9.2	3317	7/16" steel	proper	omitted	

*Proper penetration means that the stud has entered the target material and that the head of the stud is seated flush against the target material. A recorded distance for the penetration means that the stud has penetrated into the target material to that stated distance but that the head of the stud was not seated flush against the target material.

TABLE I (cont'd)

Summary Performance

Rd	Charge Type	Charge Grains	Stud No.	Target Material	Target Penetration	Pressure psi	Pressure Method
G. Modified Test Fixture							
1	WC 350	9.4	3317	7/16" steel	proper	26600	copper cylinder
2	WC 350	9.4	3317	7/16" steel	proper	22100	copper cylinder
3	WC 350	9.4	3317	7/16" steel	proper	18300	copper cylinder
4	WC 350	9.4	3317	7/16" steel	7/16"	16700	copper cylinder
5	WC 350	9.4	3317	7/16" steel	3/8"	29500	copper cylinder
6	WC 350	9.4	3317	7/16" steel	7/16"	18600	copper cylinder
H. Modified Test Fixture, Charge Established							
1	WC 350	8.5	3317	7/16" steel	proper	37000	copper cylinder
2	WC 350	8.5	3317	7/16" steel	proper	23600	copper cylinder
3	WC 350	8.5	3317	7/16" steel	proper	29400	copper cylinder
4	WC 350	8.5	3317	7/16" steel	proper	36500	copper cylinder
5	WC 350	8.5	3317	7/16" steel	7/16"	19800	copper cylinder
6	WC 350	8.5	3317	7/16" steel	proper	37200	copper cylinder
7	WC 350	8.5	3317	7/16" steel	proper	37400	copper cylinder
8	WC 350	8.5	3317	7/16" steel	proper	32400	copper cylinder
9	WC 350	8.5	3317	7/16" steel	proper	27300	copper cylinder
10	WC 350	8.5	3317	7/16" steel	proper	25000	copper cylinder
I. Modified Test Fixture, Charge Established							
1	WC 350	8.5	3317	7/16" steel	proper	34000	piezo gage
2	WC 350	8.5	3317	7/16" steel	proper	7000	piezo gage
3	WC 350	8.5	3317	7/16" steel	7/16"	8300	piezo gage
4	WC 350	8.5	3317	7/16" steel	proper	37000	piezo gage
5	WC 350	8.5	3317	7/16" steel	7/16"	27000	piezo gage
J. Modified Test Fixture, Prototype and Charge							
1	Red dot	5.0	3317	7/16" steel	7/16"	6000	piezo gage
2	Red dot	5.0	3317	7/16" steel	7/16"	missed	piezo gage
3	Red dot	5.0	3317	7/16" steel	7/16"	8060	piezo gage
4	AL-8	7.0	3317	7/16" steel	3/8"	13000	piezo gage
5	AL-8	7.0	3317	7/16" steel	3/8"	13500	piezo gage
6	AL-8	7.0	3317	7/16" steel	3/8"	12500	piezo gage
7	AL-8	7.0	3317	7/16" steel	3/8"	12500	piezo gage
8	AL-8	7.0	3317	7/16" steel	3/8"	12000	piezo gage
9	IMR-3031	8.0	3317	7/16" steel	1/4"	15800	piezo gage
10	IMR-3031	10.0	3317	7/16" steel	5/16"	missed pk.	piezo gage
K. Modified Test Fixture, Charge Established							
1	WC 240	7.7	3317	7/16" steel	proper	25500	piezo gage
2	WC 240	7.7	3317	7/16" steel	proper	19500	piezo gage
3	WC 240	7.7	3317	7/16" steel	proper	27000	piezo gage
4	WC 240	7.7	3317	7/16" steel	proper	32000	piezo gage
5	WC 240	7.7	3317	7/16" steel	proper	22000	piezo gage
6	WC 240	7.7	3317	7/16" steel	proper	25500	piezo gage
7	WC 240	7.7	3317	7/16" steel	proper	26000	piezo gage
8	WC 240	7.7	3317	7/16" steel	proper	22000	piezo gage
9	WC 240	7.7	3317	7/16" steel	proper	24000	piezo gage
10	WC 240	7.7	3317	7/16" steel	proper	23000	piezo gage
11	WC 240	7.7	3317	7/16" steel	7/16"	19000	piezo gage
12	WC 240	7.7	3317	7/16" steel	proper	28000	piezo
13	WC 240	7.7	3317	7/16" steel	proper	24500	piezo
14	WC 240	7.7	3317	7/16" steel	proper	22500	piezo
15	WC 240	7.7	3317	7/16" steel	proper	24000	piezo

TABLE I (cont'd)

Summary Performance

Rd	Charge Type	Charge Grains	Stud No.	Target Material	Target Penetration	Pressure psi	Pressure Method
	L. Modified Test Fixture, Charge Established						
1	WC 240	7.7	3317	7/16"steel	7/16"	21000	copper cylinder
2	WC 240	7.7	3317	7/16"steel	proper	23400	copper cylinder
3	WC 240	7.7	3317	7/16"steel	7/16"	18100	copper cylinder
4	WC 240	7.7	3317	7/16"steel	proper	25800	copper cylinder
5	WC 240	7.7	3317	7/16"steel	7/16"	13600	copper cylinder
6	WC 240	7.7	3317	7/16"steel	proper	41000	copper cylinder
7	WC 240	7.7	3317	7/16"steel	proper	46000	copper cylinder
8	WC 240	7.7	3317	7/16"steel	proper	21500	copper cylinder
9	WC 240	7.7	3317	7/16"steel	proper	47600	copper cylinder
10	WC 240	7.7	3317	7/16"steel	proper	42300	copper cylinder
	M. Modified Test Fixture, Charge Established with 3/4"Standoff						
1	WC 240	7.7	3317	7/16" steel	proper	17300	copper cylinder
2	WC 240	7.7	3317	7/16" steel	proper	25900	copper cylinder
3	WC 240	7.7	3317	7/16" steel	proper	18600	copper cylinder
4	WC 240	7.7	3317	7/16" steel	proper	16600	copper cylinder
5	WC 240	7.7	3317	7/16" steel	proper	16300	copper cylinder
6	WC 240	7.7	3317	7/16" steel	proper	18200	copper cylinder
7	WC 240	7.7	3317	7/16" steel	proper	16400	copper cylinder
8	WC 240	7.7	3317	7/16" steel	proper	29500	copper cylinder
9	WC 240	7.7	3317	7/16" steel	proper	23500	copper cylinder
10	WC 240	7.7	3317	7/16"steel	proper	20900	copper cylinder
11	WC 240	7.7	3317	7/16"steel	proper	15600	copper cylinder
12	WC 240	7.7	3317	7/16"steel	proper	26200	copper cylinder
13	WC 240	7.7	3317	7/16"steel	proper	28600	copper cylinder
	N. High-Low Test Fixture, Charge Established						
1	WC 240	7.7	3317	7/16"steel	7/16"	64000	copper cylinder
2	WC 240	7.7	3317	7/16"steel	7/16"	63100	copper cylinder
3	WC 240	7.7	3317	7/16"steel	7/16"	64400	copper cylinder
4	WC 240	7.7	3317	7/16"steel	3/8"	31000	piezo gage
5	WC 240	7.7	3317	7/16"steel	3/8"	37500	piezo gage
6	WC 240	7.7	3317	7/16"steel	3/8"	37000	piezo gage

TABLE II

Modified Test Fixture, Recoil and Velocity

Rd	Charge Type	Charge Grains	Stud No.	Target Material	Target Penetration	Recoil	Velocity
1	WC 240	7.7	3317	cement	3/8"	0.5 lb-sec	-
2	WC 240	7.7	3317	7/16" stl	proper	4.5 lb-sec	-
3	WC 240	7.7	3317	7/16" stl	3/8"	9.5 lb-sec	-
4	WC 240	7.7	3317	none	none	-	479 fps
5	WC 240	7.7	3317	none	none	-	534 fps

insignificant with cement as a target object, and somewhat more than a shotgun in 7/16 inch thick steel. When the stud did not penetrate steel, recoil was excessive. The muzzle velocity averaged 507 fps.

The "Pen-Gun" solved the problem of a multipurpose firing mechanism that is presumably waterproof (although not tested under water). The system was lightweight and noiseless, which was a goal of the project. The prototype stud driver weighed one pound complete and the only noise heard when it fired was the sound of the stud striking the material into which it was being driven. The one-charge one-stud goal looked feasible and appeared to be no problem. Finally, the driving mechanism was a one-shot expendable device, easy to handle because of its size and weight.

CONCLUSIONS

The results showed that the development of the stud driver progressed as planned with the exception of obtaining consistent pressures, which may well be a problem of measurement. The high-low test fixture gave promise of leading to a more uniform system, but the cancellation of the project occurred when this fixture was in an early stage of development.

Best overall results were produced by using standoff; all penetrations were proper despite inconsistent pressure measurements. The stud driver must be longer and heavier, and the extra length is equal to twice the standoff due to additional piston travel as well as extra stud travel. These are not serious problems.

The major objectives of this test program were achieved. We developed a hand-held expendable stud driving device, which will drive commercial studs or the like into structural steel, wood, concrete, cinderblock, and limestone. It is seven inches long and one inch in diameter, and weighs one pound. It can be fired with a hammer or a spring-driven firing mechanism like the "Pen-Gun".

APPENDIX

TABLE A-1

Original Stud Driver Test Fixture

Rd	Charge (grain)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration	Pull-out force (lb)
1	7.6	WC350	3335	none	cinder	9000	copper cylinder	Proper	-
2	8.8	WC350	3335	none	cinder	15600	copper cylinder	3/16"	-
3	8.8	WC350	3335	none	cinder	9000	copper cylinder	Proper	-
4	8.8	WC350	3335	none	concrete	11000	copper cylinder	3/8"	-
5	8.8	WC340	3335	none	concrete	9100	copper cylinder	3/8"	-
6	10.4	WC350	3335	none	concrete	10300	copper cylinder	Proper	-
7	10.4	WC350	3335	none	concrete	20100	copper cylinder	Proper	-
8	7.6	WC350	3335	none	concrete	13100	copper cylinder	Proper	-
9	7.6	WC350	3335	none	concrete	10300	copper cylinder	Proper	-
10	7.6	WC350	3335	none	concrete	9000	copper cylinder	Proper	-
11	7.6	WC350	3335	none	concrete	9000	copper cylinder	Proper	-
12	7.6	WC350	3335	none	limestone	9000	copper cylinder	Proper	-
13	7.6	WC350	3335	none	limestone	3100	copper cylinder	Proper	-
14	7.6	WC350	3335	none	limestone	9400	copper cylinder	Proper	-
15	7.6	WC350	3335	none	limestone	8600	copper cylinder	Proper	-
16	7.6	WC350	3335	none	limestone	10000	copper cylinder	Proper	-
17	7.6	WC350	3335	none	limestone	10200	copper cylinder	Proper	-
18	7.6	WC350	3335	none	limestone	9300	copper cylinder	Proper	-
19	7.6	WC350	3335	none	limestone	8700	copper cylinder	Proper	-
20	7.6	WC350	3335	none	limestone	9500	copper cylinder	Proper	-
21	7.6	WC350	3335	none	limestone	6500	copper cylinder	Proper	-
22	4.0	WC350	3601	none	limestone	4000	copper cylinder	1/8"	-
23	4.5	WC350	3601	none	limestone	4200	copper cylinder	Proper	-
24	5.0	WC350	3601	none	limestone	4200	copper cylinder	3/8"	-
25	5.0	WC350	3601	none	limestone	5300	copper cylinder	3/8"	-
26	5.0	WC350	3601	none	limestone	4900	copper cylinder	3/8"	-
27	5.0	WC350	3601	none	limestone	3000	copper cylinder	Proper	-
28	5.0	WC350	3601	none	limestone	5700	copper cylinder	Proper	-
29	5.0	WC350	3601	none	limestone	7000	copper cylinder	3/8"	-
30	7.6	WC350	3317	none	limestone	12600	copper cylinder	Proper	-
31	5.0	WC350	3601	none	wood	3100	copper cylinder	3/8"	-
32	7.6	WC350	3317	none	wood	15500	copper cylinder	7/16"	-
33	5.0	WC350	3317	none	wood	7300	copper cylinder	3/7"	-
34	5.0	WC350	5/2965	none	limestone	4800	copper cylinder	1/8"	770
35	5.0	WC350	5/2965	none	limestone	7300	copper cylinder	1/8"	850
36	5.0	WC350	5/2965	none	limestone	5900	copper cylinder	1/8"	-
37	5.0	WC350	5/2965	none	limestone	4800	copper cylinder	1/8"	980
38	5.0	WC350	5/2965	none	limestone	5300	copper cylinder	1/8"	-
39	5.0	WC350	3318	none	limestone	3100	copper cylinder	1/16"	-
40	5.0	WC350	5/2965	none	limestone	6800	copper cylinder	1/8"	-
41	5.0	WC350	5/2965	none	concrete	8200	copper cylinder	1/16"	-
42	5.0	WC350	5/2965	none	concrete	8000	copper cylinder	1/16"	-
43	7.6	WC350	5/2965	none	concrete	19600	copper cylinder	Proper	230
44	7.6	WC350	5/2965	none	concrete	21100	copper cylinder	Proper	-
45	6.0	WC350	5/2965	none	concrete	12000	copper cylinder	1/8"	806

TABLE A-I (cont'd)

Rd	Charge (grain)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration	Pull-out force (lb)
46	6.0	WC350	5/2965	none	concrete	11500	copper cylinder	1/8"	-
47	6.0	WC350	5/2965	none	concrete	9200	copper cylinder	Proper	1630
48	6.0	WC350	5/2965	none	concrete	9500	copper cylinder	Proper	720
49	6.0	WC350	5/2965	none	cinders	9900	copper cylinder	3/8"	780
50	6.0	WC350	5/2965	none	wood	7200	copper cylinder	3/8"	-
51	6.0	WC350	5/2965	none	limestone	10100	copper cylinder	Proper	1220
52	6.0	WC350	5/2965	none	cinder	8600	copper cylinder	Proper	400
53	6.0	WC350	5/2965	none	wood and washer	4200	copper cylinder	Proper	108
54	6.0	WC350	5/2965 & grooved	none	wood and washer	9200	copper cylinder	Proper	160
55	6.0	WC350	5/2965	none	limestone & washer	4200	copper cylinder	1/8"	730
56	6.0	WC350	5/2965	none	cinder & washer	4500	copper cylinder	Proper	-
57	6.0	WC350	3317	none	limestone	9800	copper cylinder	Proper	-
58	6.0	WC350	3317	none	wood & washer	3300	copper cylinder	1/8"	-
59	6.0	WC350	3317	none	wood & 1/16 steel	11400	copper cylinder	Proper	-
60	6.0	WC350	3317	none	5/16" steel	8300	copper cylinder	3/16"	-
61	6.0	WC350	3317	none	5/16" steel	10600	copper cylinder	[illegible]	-
62	7.6	WC350	3317	none	5/16" steel	18500	copper cylinder	5/16"	-
63	7.6	WC350	3317	none	5/16" steel	18300	copper cylinder	5/16"	-
64	8.8	WC350	3317	none	5/16" steel	27000	copper cylinder	Proper	-
65	7.6	WC350	5/2965	none	5/16" steel	23600	copper cylinder	7/16"	-
66	8.8	WC350	5/2965	none	5/16" steel	26100	copper cylinder	3/8"	990
67	8.8	WC350	3317	none	wood and 1/16 steel	12600	copper cylinder	3/8"	-
68	8.8	WC350	5/2965	none	concrete and washer	11700	copper cylinder	1/8"	740
69	8.8	WC350	3317	none	7/16 steel	27100	copper cylinder	3/8"	-
70	8.8	WC350	3317	none	7/16 steel	29400	copper cylinder	3/8"	-
71	9.2	WC350	3317	none	7/16 steel	22800	copper cylinder	3/8"	-
72	9.2	WC350	3317	none	7/16 steel	23400	copper cylinder	3/8"	-
73	8.8	WC350	5/2965	none	7/16 steel	29400	copper cylinder	15/32"	-
74	9.2	WC350	5/2965	none	7/16 steel	30000	copper cylinder	15/32"	-
75	8.8	WC350	5/2965	none	[illegible] steel	21600	copper cylinder	Proper	-
76	10.0	WC350	5/2965	none	7/16 steel	23200	copper cylinder	19/32"	-
77	10.4	WC350	5/2965	none	7/16 steel	35100	copper cylinder	Proper	-
78	10.4	WC350	3317	none	7/16 steel	26600	copper cylinder	1/8"	-
79	10.4	WC350	3317	none	7/16 steel	31500	copper cylinder	7/16"	-
80	10.4	WC350	3317	none	7/16 steel	31100	copper cylinder	Proper	-
81	9.2	WC350	3317	none	7/16 steel	19300	copper cylinder	7/16"	-
82	9.2	WC350	3317	none	7/16 steel	18700	copper cylinder	7/16"	-
83	9.2	WC350	3317	none	7/16 steel	24400	copper cylinder	Proper	-
84	9.2	WC350	3317	none	7/16 steel	23900	copper cylinder	Proper	-
85	9.2	WC350	3317	none	7/16 steel	26800	copper cylinder	7/16"	-
86	9.2	WC350	3317	none	7/16 steel	21800	copper cylinder	7/16"	-
87	9.5	WC350	3317	none	7/16 steel	17000	piezo gage	7/16"	-
88	9.5	WC350	3317	none	7/16 steel	14000	piezo gage	1/16"	-
89	9.5	WC350	3317	none	7/16 steel	19500	piezo gage	Proper	-
90	9.5	WC350	3317	none	7/16 steel	19000	piezo gage	Proper	-
91	9.5	WC350	3317	none	7/16 steel	17500	piezo gage	7/16"	-

TABLE A-II

Modified Stud Driver Test Fixture

Rd.	Charge (grain)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration
1	9.0	WC340	3317	none	7/16" steel	17700	copper cylinder	7/16"
2	9.0	WC340	3317	none	7/16" steel	60600	copper cylinder	3/8"
3	9.0	WC340	3317	none	7/16" steel	17700	copper cylinder	7/16"
4	9.0	WC340	3317	none	7/16" steel	18300	copper cylinder	7/16"
5	9.0	WC340	3317	none	7/16" steel	23700	copper cylinder	7/16"
6	9.2	WC340	3317	none	7/16" steel	22300	copper cylinder	7/16"
7	9.2	WC340	3317	none	7/16" steel	25400	copper cylinder	7/16"
8	9.2	WC340	3317	none	7/16" steel	18100	copper cylinder	7/16"
9[a]	9.2	WC340	hardened	none	7/16" steel	55200	copper cylinder	7/16"
10	9.2	WC340	3317	7/16" piston	7/16" steel	50000	copper cylinder	1/16"
11	9.2	WC340	3317	none	7/16" steel	19900	copper cylinder	7/16"
12	9.2	WC340	3317	none	7/16" steel	17300	copper cylinder	7/16"
13	9.2	WC340	3317	none	7/16" steel	48600	copper cylinder	3/8"
14	9.2	WC340	3317	none	7/16" steel	19900	copper cylinder	7/16"
15	9.2	WC340	3317	none	7/16" steel	20600	copper cylinder	7/16"
16	9.2	WC340	3317	none	7/16" steel	48400	copper cylinder	3/8"
17	9.2	WC340	3317	none	7/16" steel	16700	copper cylinder	7/16"
18	9.2	WC340	3317	none	7/16" steel	20600	copper cylinder	3/8"
19	9.4	WC340	3317	none	7/16" steel	26600	copper cylinder	Proper
20	9.4	WC340	3317	none	7/16" steel	22100	copper cylinder	Proper
21	9.4	WC340	3317	none	7/16" steel	18300	copper cylinder	Proper
22	9.4	WC340	3317	none	7/16" steel	16700	copper cylinder	7/16"
23	9.4	WC340	3317	none	7/16" steel	29500	copper cylinder	3/8"
24	9.4	WC340	3317	none	7/16" steel	18600	copper cylinder	7/16"
25	9.4	WC340	3317	7/16" stud	7/16" steel	11700	copper cylinder	7/16"
26	9.4	WC350	3318	3/16" stud	7/16" steel	56600	copper cylinder	1/8"
27	9.4	WC350	3318	3/16" stud	7/16" steel	47800	copper cylinder	1/8"
28	9.4	WC350	3318	3/16" stud	7/16" steel	51600	copper cylinder	Proper
29	9.4	WC350	3318	3/16" stud	7/16" steel	24100	copper cylinder	Proper
30	9.4	WC350	3318	3/16" stud	7/16" steel	48200	copper cylinder	Proper
31	9.4	WC350	3318	3/16" stud	7/16" steel	16900	copper cylinder	7/16"
32	9.4	WC350	3318	3/16" stud	7/16" steel	43400	copper cylinder	Proper
33	9.4	WC350	3317	1/8" stud	7/16" steel	58000	copper cylinder	Proper
34	9.4	WC350	3317	1/8" stud	7/16" steel	54000	copper cylinder	Proper
35	9.4	WC350	3317	1/8" stud	7/16" steel	63700	copper cylinder	Proper
36	8.0	WC350	3317	1/8" stud	7/16" steel	24100	copper cylinder	7/16"
37	8.0	WC350	3317	1/8" stud	7/16" steel	29600	copper cylinder	7/16"
38	8.4	WC350	3317	1/8" stud	7/16" steel	4800	piezo gage	Proper
39	8.4	WC350	3317	1/8" stud	7/16" steel	32000	piezo gage	Proper
40	8.4	WC350	3317	1/8" stud	7/16" steel	no piston	piezo gage	
41	8.4	WC350	3317	1/8" stud	7/16" steel	20000	piezo gage	7/16"
42	8.4	WC350	3317	1/8" stud	7/16" steel	16000	piezo gage	7/16"
43	8.5	WC350	3317	1/8" stud	7/16" steel	34000	piezo gage	Proper
44	8.5	WC350	3317	1/8" stud	7/16" steel	7000	piezo gage	Proper
45	8.5	WC350	3317	1/8" stud	7/16" steel	8300	piezo gage	7/16"

[a] Pin or stud failed

TABLE A- II (cont'd)

Rd.	Charge (grain)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration
46	8.5	WC350	3317	1/8"stud	7/16" steel	37000	piezo gage	Proper
47	8.5	WC350	3317	1/8"stud	7/16" steel	27000	piezo gage	7/16"
48	8.5	WC350	3317	1/8"stud	7/16" steel	37000	copper cylinder	Proper
49	8.5	WC350	3317	1/8"stud	7/16" steel	33600	copper cylinder	Proper
50	8.5	WC350	3317	1/8"stud	7/16" steel	29400	copper cylinder	Proper
51	8.5	WC350	3317	1/8"stud	7/16" steel	36500	copper cylinder	Proper
52	8.5	WC350	3317	1/8"stud	7/16" steel	19800	copper cylinder	7/16"
53	8.5	WC350	3317	1/8"stud	7/16" steel	32700	copper cylinder	Proper
54	8.5	WC350	3317	1/8"stud	7/16" steel	37400	copper cylinder	Proper
55	8.5	WC350	3317	1/8"stud	7/16" steel	32400	copper cylinder	Proper
56	8.5	WC350	3317	1/8"stud	7/16" steel	27300	copper cylinder	Proper
57	8.5	WC350	3317	1/8"stud	7/16" steel	25000	copper cylinder	Proper
58	8.5	WC350	3317	1/8"stud	7/16" steel	40200	copper cylinder	Proper
59	8.5	WC350	3317	1/8"stud	7/16" steel	32200	copper cylinder	Proper
60	8.5	WC350	3317	1/8"stud	7/16" steel	missed	copper cylinder	Proper
61	8.5	WC350	3317	1/8"stud	7/16" steel	24600	copper cylinder	Proper
62	8.5	WC350	3317	1/8"stud	7/16" steel	25400	copper cylinder	7/16"
63	8.5	WC350	3317	1/8"stud	7/16" steel	11400	copper cylinder	7/16"
64	8.5	WC350	3317	1/8"stud	7/16" steel	29200	copper cylinder	7/16"
65	8.5	WC350	3317	1/8"stud	7/16" steel	21400	copper cylinder	7/16"
66	8.5	WC350	3317	1/8"stud	7/16" steel	47200	copper cylinder	7/16"
67	8.5	WC350	3317	1/8"stud	7/16" steel	40200	copper cylinder	7/16"
68	8.5	WC350	3317	1/8"stud	7/16" steel	35200	copper cylinder	7/16"
69	8.5	WC350	3317	1/8"stud	7/16" steel	7000	piezo gage	7/16"
70	8.5	WC350	3317	1/8"stud	7/16" steel	7000	piezo gage	7/16"
71	8.5	WC350	3317	1/8"stud	7/16" steel	5000	piezo gage	7/16"
72	8.5	WC350	3317	1/8"stud	7/16" steel	missed	piezo gage	7/16"
73	8.5	WC350	3317	1/8"stud	7/16" steel	50000	piezo gage	7/16"
74	8.5	WC350	3317	1/8"stud	7/16" steel	4000	piezo gage	7/16"
75	8.5	WC350	3317	1/8"stud	7/16" steel	6000	piezo gage	7/16"
76	8.5	WC350	3317	1/8"stud	7/16" steel	missed	piezo gage	Proper
77	5.0	red dot	3317	1/8"stud	7/16" steel	6000	piezo gage	7/16"
78	5.0	red dot	3317	1/8"stud	7/16" steel	missed	piezo gage	7/16"
79	5.0	red dot	3317	1/8"cart.	7/16" steel	8000	piezo gage	7/16"
80	8.6	WC350	3317	1/8"stud	7/16" steel	42500	copper cylinder	Proper
81	8.6	WC350	3317	1/8"stud	7/16" steel	35100	copper cylinder	Proper
82	8.6	WC350	3317	1/8"cart.	7/16" steel	19200	copper cylinder	3/8"
83	8.6	WC350	3317	1/8"cart.	7/16" steel	19200	copper cylinder	3/8"
84	8.6	WC350	3317	1/8"cart.	7/16" steel	20700	copper cylinder	3/8"
85	8.6	WC350	3317	1/8"cart.	7/16" steel	20300	copper cylinder	3/8"
86	8.6	WC350	3317	1/8"cart.	7/16" steel	missed	piezo gage	Proper
87	8.6	WC350	3317	1/8"cart.	7/16" steel	missed	piezo gage	Proper
88	8.6	WC350	3317	1/8"cart.	7/16" steel	missed	piezo gage	3/8"
89	8.5	WC350	3317	1/8"cart.	7/16" steel	missed	piezo gage	3/8"
90	8.5	WC350	3317	1/8"cart.	7/16" steel	missed	piezo gage	7/16"

TABLE A-II (cont'd)

Rd.	Charge (gram)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration
91	7.0	AL-8	3317	1/8"stud	7/16" steel	13000	piezo gage	3/8"
92	7.0	AL-8	3317	1/8"stud	7/16" steel	13400	piezo gage	3/8"
93	7.0	AL-8	3317	1/8"stud	7/16" steel	12500	piezo gage	3/8"
94	7.0	AL-8	3317	1/8"stud	7/16" steel	12500	piezo gage	3/8"
95	7.0	AL-8	3317	1/8"stud	7/16" steel	12000	piezo gage	3/8"
96[b]	8.0	AL-8	3317	1/8"stud	7/16" steel	14500	piezo gage	
97	8.0	AL-8	3317	1/8"stud	7/16" steel	17000	peizo gage	7/16"
98	8.5	WC350	3317	1/8"stud	7/16" steel	36500	piezo gage	Proper
99	8.5	WC350	3317	1/8"stud	7/16" steel	32000	piezo gage	Proper
100	8.5	WC350	3317	1/8"stud	7/16" steel	39500	piezo gage	Proper
101	8.5	WC350	3317	1/8"stud	7/16" steel	35000	piezo gage	Proper
102	8.5	WC350	3317	1/8"stud	7/16" steel	52000	piezo gage	Proper
103	8.5	WC350	3317	1/8"stud	7/16" steel	47000	piezo gage	Proper
104	8.5	WC350	3317	1/8"stud	7/16" steel	36500	piezo gage	Proper
105	8.5	WC350	3317	1/8"stud	7/16" steel	57000	piezo gage	Proper
106	8.5	WC350	3317	1/8"stud	1/16" steel	26000	piezo gage	Proper
107	8.5	WC350	3317	1/8"stud	1/16" steel	48000	piezo gage	Proper
108	8.5	WC350	3317	1/8"stud	1/16" steel	35500	piezo gage	Proper
109	8.5	WC350	3317	1/8"stud	1/16" steel	26000	piezo gage	Proper
110	8.5	WC350	3317	1/8"stud	1/16" steel	21000	piezo gage	7/16"
111	8.5	WC350	3317	1/8"stud	1/16" steel	13000	piezo gage	7/16"
112	8.5	WC350	3317	1/8"stud	1/16" steel	45500	piezo gage	Proper
113	8.5	WC350	3317	1/8"stud	1/16" steel	32000	piezo gage	Proper
114[c]	8.5	WC350	3317	1/8"stud	1/16" steel	14000	piezo gage	1/4"
115	8.6	IMR3031	3317	1/8"stud	1/16" steel	15800	copper cylinder	1/4"
116[d]	10.0	IMR3031	3317	1/8"stud	1/16" steel	2500	piezo gage	5/16"
117	6.0	WC240	3317	1/8"stud	1/16" steel	13000	piezo gage	7/16"
118	6.0	WC240	3317	1/8"stud	1/16" steel	missed	piezo gage	7/16"
119	7.5	WC240	3317	1/8"stud	1/16" steel	20000	piezo gage	Proper
120	7.5	WC240	3317	1/8"stud	1/16" steel	missed	piezo gage	Proper
121	7.5	WC240	3317	1/8"stud	7/16" steel	17000	piezo gage	7/16"
122	7.5	WC240	3317	1/8"stud	7/16" steel	missed	piezo gage	7/16"
123	7.5	WC240	3317	1/8"stud	7/16" steel	23000	piezo gage	Proper
124	7.5	WC240	3317	1/8"stud	7/16" steel	2450	piezo gage	Proper
125	7.5	WC240	3317	1/8"stud	7/16" steel	19000	piezo gage	7/16"
126	7.5	WC240	3317	1/8"stud	7/16" steel	12000	piezo gage	7/16"
127	7.5	WC240	3317	1/8"stud	7/16"steel	19000	piezo gage	7/16"
128	7.5	WC240	3317	1/8"stud	7/16"steel	24000	piezo gage	Proper
129	7.5	WC240	3317	1/8"stud	7/16"steel	26000	piezo gage	Proper
130	7.5	WC240	3317	1/8"stud	7/16"steel	24500	piezo gage	Proper
131	7.7	WC240	3317	1/8"stud	7/16"steel	25500	piezo gage	Proper
132	7.7	WC240	3317	1/8"stud	7/16"steel	19500	piezo gage	Proper
133	7.7	WC240	3317	1/8"stud	7/16"steel	27000	piezo gage	Proper
134	7.7	WC240	3317	1/8"stud	7/16"steel	32000	piezo gage	Proper
135	7.7	WC240	3317	1/8"stud	7/16"steel	22000	piezo gage	Proper
136	7.7	WC240	3317	1/8"stud	7/16"steel	25500	piezo gage	Proper
137	7.7	WC240	3317	1/8"stud	7/16"steel	26000	piezo gage	Proper
138	7.7	WC240	3317	1/8"stud	7/16"steel	22000	piezo gage	Proper
139	7.7	WC240	3317	1/8"stud	7/16"steel	24000	piezo gage	Proper
140	7.7	WC240	3317	1/8"stud	7/16"steel	23000	piezo gage	Proper

[b]no stud

[c]piston failed

[d]time too slow

TABLE A-II (cont'd)

Rd.	Charge (grain)	Prop.	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration
141	7.7	WC240	3317	1/8"stud	7/16" steel	19000	piezo-gage	7/16"
142	7.7	WC240	3317	1/8"stud	7/16" steel	28000	piezo-gage	Proper
143	7.7	WC240	3317	1/8"stud	7/16" steel	24500	piezo-gage	Proper
144	7.7	WC240	3317	1/8"stud	7/16" steel	22500	piezo-gage	Proper
145	7.7	WC240	3317	1/8"stud	7/16" steel	24000	piezo-gage	Proper
146	7.7	WC240	3317	1/8"stud	7/16" steel	27400	copper-cylinder	Proper
147	7.7	WC240	3317	1/8"stud	7/16" steel	25400	copper-cylinder	7/16"
148	7.7	WC240	3317	1/8"stud	7/16" steel	26200	copper-cylinder	Proper
149	7.7	WC240	3317	1/8"stud	7/16" steel	29700	copper-cylinder	Proper
150	7.7	WC240	3317	1/8"stud	7/16" steel	24400	copper-cylinder	7/16"
151	7.7	WC240	3317	1/8"stud	7/16" steel	25700	copper-cylinder	7/16"
152	7.7	WC240	3317	1/8"stud	7/16" steel	21000	copper-cylinder	7/16"
153	7.8	WC240	3317	1/8"stud	7/16" steel	27700	copper-cylinder	Proper
154	7.8	WC240	3317	1/8"stud	7/16" steel	29500	copper-cylinder	Proper
155	7.8	WC240	3317	1/8"stud	7/16" steel	28400	copper-cylinder	Proper
156	7.8	WC240	3317	1/8"stud	7/16" steel	24300	copper-cylinder	7/16"
157	7.8	WC240	3317	1/8"stud	7/16" steel	23400	copper-cylinder	7/16"
158	7.8	WC240	3317	1/8"stud	7/16" steel	22200	copper-cylinder	7/16"
159	7.7	WC240	3317	1/8"stud	7/16" steel	21900	copper-cylinder	7/16"
160	7.7	WC240	3317	3/4"stud	7/16" steel	17300	copper-cylinder	Proper
161	7.7	WC240	3317	3/4"stud	7/16" steel	25900	copper-cylinder	Proper
162	7.7	WC240	3317	3/4"stud	7/16" steel	18600	copper-cylinder	Proper
163	7.7	WC240	3317	3/4"stud	7/16" steel	16600	copper-cylinder	Proper
164	7.7	WC240	3317	3/4"stud	7/16" steel	16300	copper-cylinder	Proper
165	7.7	WC240	3317	3/4"stud	7/16" steel	18200	copper-cylinder	Proper
166	7.7	WC240	3317	3/4"stud	7/16" steel	11100	copper-cylinder	1/8"
167	7.7	WC240	3317	3/4"stud	7/16" steel	16400	copper-cylinder	Proper
168	7.7	WC240	3317	3/4"stud	7/16" steel	29500	copper-cylinder	Proper
169	7.7	WC240	3317	3/4"stud	7/16" steel	23500	copper-cylinder	Proper
170	7.7	WC240	3317	3/4"stud	7/16" steel	20900	copper-cylinder	Proper
171	7.7	WC240	3317	3/4"stud	7/16" steel	15600	copper-cylinder	Proper
172	7.7	WC240	3317	3/4"stud	7/16" steel	26200	copper-cylinder	Proper
173	7.7	WC240	3317	3/4"stud	7/16" steel	28600	copper-cylinder	Proper
174	7.7	WC240	3318	3/4"stud	7/16" steel	27000	copper-cylinder	Proper
175	7.7	WC240	3318	3/4"stud	7/16" steel	27000	copper-cylinder	Proper
176	7.7	WC240	3318	3/4"stud	7/16" steel	17500	copper-cylinder	Proper
177	7.7	WC240	3318	3/4"stud	7/16" steel	16700	copper-cylinder	7/16"
178	7.7	WC240	3317	none	7/16" steel	35200	copper-cylinder	Proper
179	7.7	WC240	331.	none	7/16" steel	36900	copper-cylinder	7/16"
180	7.7	WC240	3317	none	7/16" steel	35600	copper-cylinder	Proper
181	7.7	WC240	3317	none	7/16" steel	21000	copper-cylinder	7/16"
182	7.7	WC240	3317	none	7/16" steel	23400	copper-cylinder	Proper
183	7.7	WC240	3317	none	7/16" steel	18100	copper-cylinder	7/16"
184	7.7	WC240	3317	none	7/16" steel	25800	copper-cylinder	Proper
185	7.7	WC240	3317	none	7/16" steel	13600	copper-cylinder	7/16"
186	7.7	WC240	3317	none	7/16" steel	41000	copper-cylinder	Proper
187	7.7	WC240	3317	none	7/16" steel	46000	copper-cylinder	Proper
188	7.7	WC240	3317	none	7/16" steel	21500	copper-cylinder	Proper
189	7.7	WC240	3317	none	7/16" steel	47600	copper-cylinder	Proper
190	7.7	WC240	3317	none	7/16" steel	42300	copper cylinder	Proper

TABLE A-III. High-Low Stud Driver Test Fixture

Rd	Charge (grain)	Prop	Stud No.	Standoff (in)	Material	Pressure (psi)	Pressure System	Penetration
1	5.0	WC240	3317	none	7/16" steel	30400	copper cylinder	3/8"
2	7.7	WC240	3317	none	7/16" steel	64000	copper cylinder	7/16"
3	7.7	WC240	3317	1/8" stud	7/16" steel	63100	copper cylinder	7/16"
4	7.7	WC240	3317	1/8" stud	7/16" steel	64400	copper cylinder	7/16"
5	5.5	WC240	3317	1/8" stud	7/16" steel	27000	copper cylinder	3/8"
6	5.5	WC240	3317	1/8" stud	7/16" steel	25800	copper cylinder	3/8"
7	5.5	WC240	3317	1/8" stud	7/16" steel	27300	copper cylinder	3/8"
8[a]	5.5	WC240	No Stud	1/8" stud	7/16" steel	25900	copper cylinder	
9	5.5	WC240	3317	1/4" stud	7/16" steel	29300	copper cylinder	3/8"
10	5.5	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
11	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
12	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
13	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
14	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
15	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
16	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
17	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
18	7.7	WC240	3317	none	7/16" steel	missed	piezo gage	3/8"
19	7.7	WC240	3317	none	7/16" steel	31000	piezo gage	3/8"
20	7.7	WC240	3317	none	7/16" steel	37500	piezo gage	3/8"
21	7.7	WC240	3317	none	7/16" steel	37000	piezo gage	3/8"
22	7.7	WC240	3317	1" cart.	7/16" steel	10300	copper cylinder	1/8"
23	7.7	WC240	3317	1" cart.	7/16" steel	9500	copper cylinder	3/16"
24	7.7	WC240	3317	1" cart.	7/16" steel	10900	copper cylinder	1/8"
25	7.7	WC240	3317	1" cart.	7/16" steel	11100	copper cylinder	1/8"
26	7.7	WC240	3317	1" cart.	7/16" steel	11100	copper cylinder	1/8"
27	7.7	WC240	3317	1/4" cart.	7/16" steel	21400	copper cylinder	3/8"

[a]no stud

Preprototype Stud Driver

Rd.	Charge (grain)	Prop.	Stud.No.	Stand-off (in)	Material	Pressure (psi)	Pressure System	Penetration
1	5.0	WC350	3317	none	limestone	none	none	1/8"
2	6.0	WC350	3317	none	limestone	21960	strain gage	1/8"
3	7.0	WC350	3317	none	limestone	29730	strain gage	Proper
4	10.4	WC350	3317	none	7/16" steel	none	none	Proper
5	10.4	WC350	3317	none	7/16" steel	none	none	1/8"
6	5.0	WC350	3317	none	7/16" steel	none	none	1/8"
7	7.0	WC350	3317	none	7/16" steel	none	none	1/4"
8	8.8	WC350	3317	none	7/16" steel	none	none	3/8"
9	9.5	WC350	3317	none	7/16" steel	none	none	3/8"
10	9.0	WC350	3317	none	7/16" steel	none	none	7/16"
11	9.2	WC350	3317	none	7/16" steel	none	none	Proper
12	9.1	WC350	3317	none	7/16" steel	none	none	Proper
13	9.0	WC350	3317	none	7/16" steel	none	none	7/16"
14	9.0	WC350	3317	none	7/16" steel	none	none	Proper
15	9.0	WC350	3317	none	7/16" steel	none	none	1/4"
16	9.0	WC350	3317	none	7/16" steel	none	none	7/16"
17	9.0	WC350	3317	none	7/16" steel	none	none	7/16"
18	9.1	WC350	3317	none	7/16" steel	none	none	3/8"
19	9.1	WC350	3317	none	7/16" steel	none	none	3/8"
20	9.1	WC350	3317	none	7/16" steel	none	none	5/16"
21	9.1	WC350	3317	none	7/16" steel	none	none	3/8"
22	9.2	WC350	3317	none	7/16" steel	none	none	3/8"
23	9.2	WC350	3317	none	7/16" steel	none	none	Proper
24	9.2	WC350	3317	none	7/16" steel	none	none	Proper
25	9.2	WC350	3317	none	7/16" steel	none	none	Proper
26	9.2	WC350	3317	none	7/16" steel	none	none	3/8"
27	9.2	WC350	3317	none	7/16" steel	none	none	3/8"
28	9.2	WC350	3317	none	7/16" steel	none	none	Proper
29	9.2	WC350	3317	none	cinder	none	none	7/16"
30	9.2	WC350	3317	none	7/16" steel	none	none	7/16"
31	9.2	WC350	3317	none	7/16" steel	none	none	Proper
32	9.2	WC350	3317	none	7/16" steel	none	none	Proper

Figure A-1. View Showing 1-3/4 Inch Studs Driven By the Test Fixture Into 7/16 Inch Thick Commercial Structural Steel Channel Section

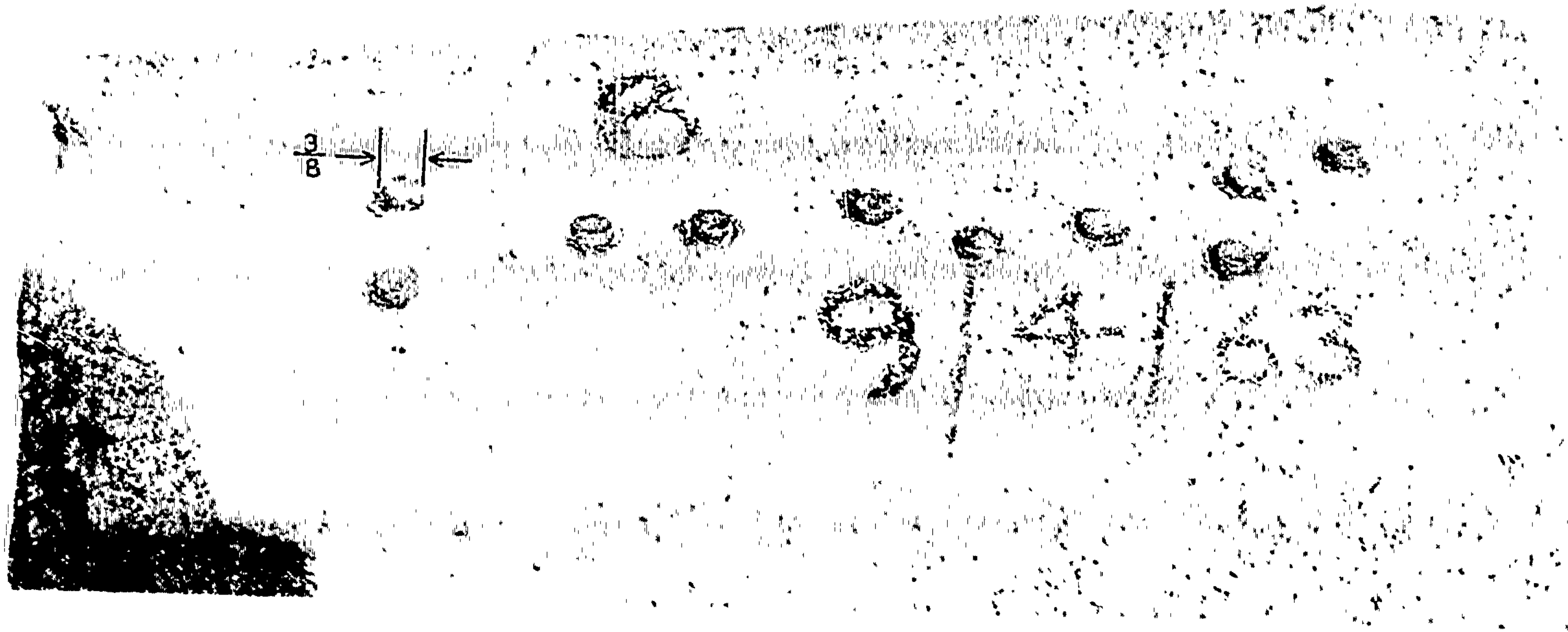


Figure A-2. View Showing 1-3/4 Inch Studs Driven By Test Fixture Into Limestone Building Block

END

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2-5-74

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